

30 C

Cell Division, Genetics, and Molecular Biology

Cancer is a broad group of diseases associated with the uncontrolled, unregulated growth of cells. Much more active than normal cells, cancer cells divide at rates that far exceed those of the parent cells from which they arose. Cancer cells also do not mature into specific cell types, as do normal cells. Cancer cells cannot carry out some of the functions of normal cells, which in turn can seriously affect a patient's health.

Cancer research aims at understanding how cells become cancer cells, and how they differ from normal cells. A research team at the University of Alberta, led by Dr. Mark Glover, is making significant contributions to our knowledge of one form of breast cancer. People at risk of developing this form of breast cancer have a mutation in a particular gene, which in turn directs the production of a mutant protein. Dr. Glover's group created the first three-dimensional model of the part of this protein that is involved in cancer development. This knowledge may lead to a method to screen patients for this type of cancer early on.

As you progress through the unit, think about these focusing questions:

- What cellular processes allow for reproduction and growth of an organism?
- What regulates the transmission of genetic information from one generation to the next?
- How is DNA responsible for the production of proteins?

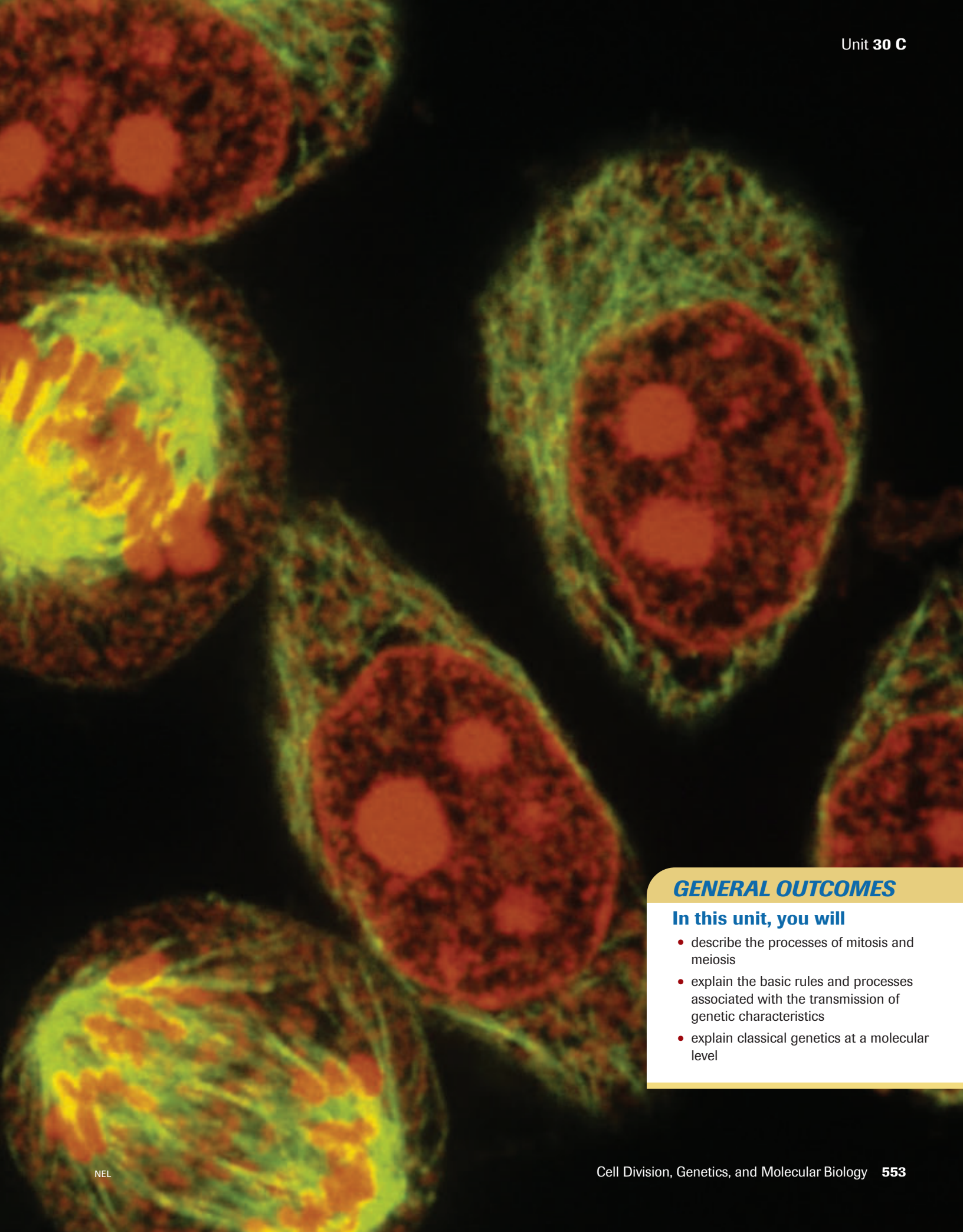
UNIT 30 C PERFORMANCE TASK

Investigating Human Traits

Genetics allows us to understand and predict the inheritance of traits. This kind of information can be very important for traits that cause health problems, such as cancer. How can human genetic traits be investigated? What do the patterns of inheritance of some common traits tell us about the genes that determine those traits? At the end of this unit, you may apply your skills and knowledge to complete this Performance Task.

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GENERAL OUTCOMES

In this unit, you will

- describe the processes of mitosis and meiosis
- explain the basic rules and processes associated with the transmission of genetic characteristics
- explain classical genetics at a molecular level

► Unit 30 C

Cell Division, Genetics, and Molecular Biology

ARE YOU READY?

These questions will help you find out what you already know, and what you need to review, before you continue with this unit.

Knowledge

1. Identify the cell structures shown in **Figure 1** and explain the importance or function of each.

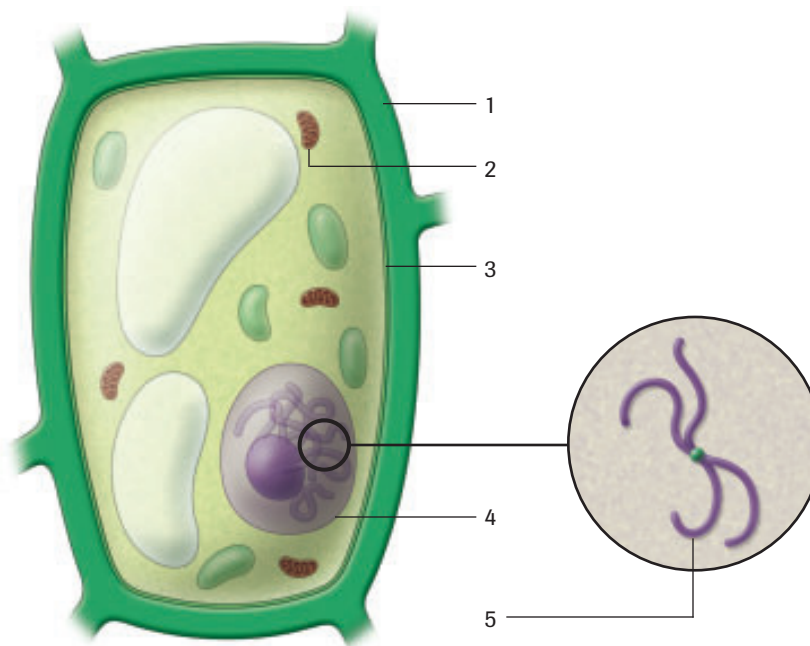


Figure 1

2. (a) Organize the following structures from largest to smallest: organ, chromosome, organism, nucleus, tissue, DNA molecule, cell, gene.
(b) Copy **Figure 2**. Use the listed structures in (a) as labels for your diagram.

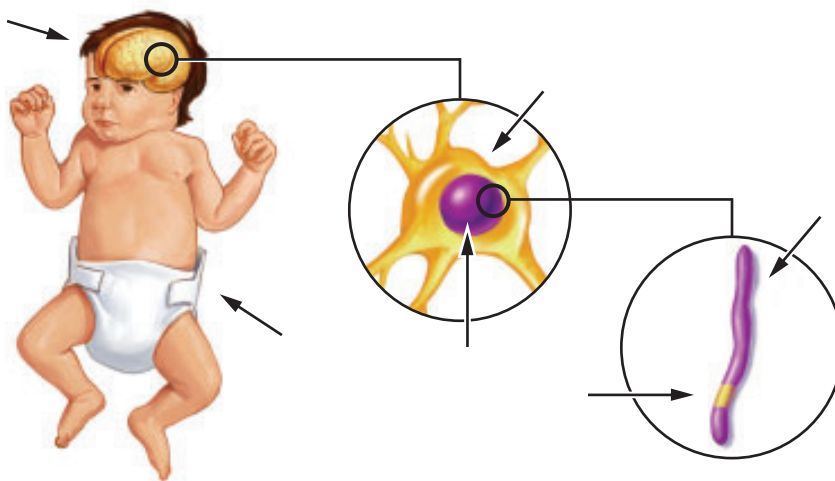


Figure 2

3. If a human muscle cell contains 46 chromosomes, indicate the number of chromosomes that you would expect to find in the cells shown in **Figures 3, 4, 5,** and **6**, on the next page.

► Prerequisites

Concepts

- DNA, genes, chromosomes
- sexual reproduction
- asexual reproduction
- adaptations and variations
- traits
- nature versus nurture

Skills

- relate biological diversity to genetic diversity
- probability

You can review prerequisite concepts and skills on the Nelson Web site and in the Appendices.

A Unit Pre-Test is also available online.

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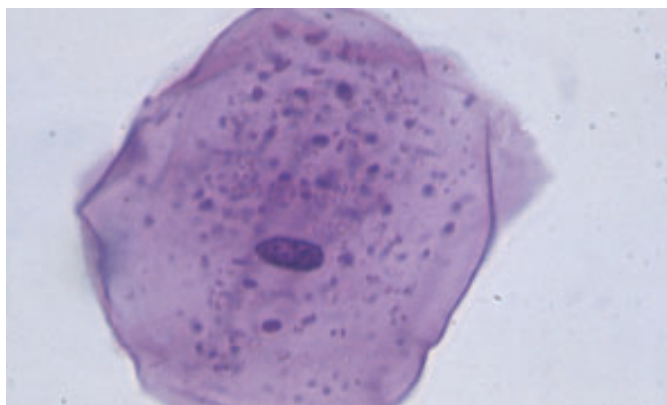


Figure 3
Skin cell, 450×



Figure 4
Sperm cell, 1000×

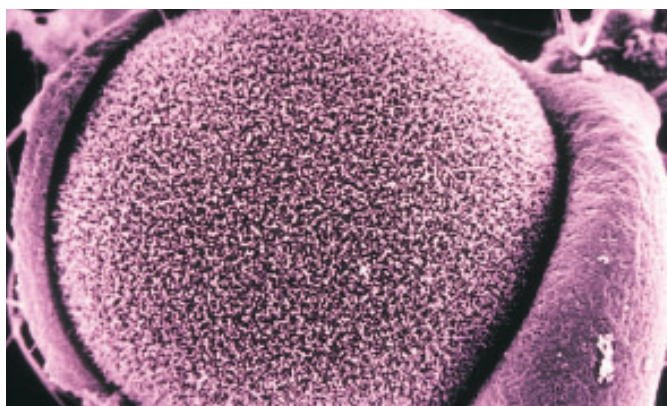


Figure 5
Unfertilized egg cell, 2000×

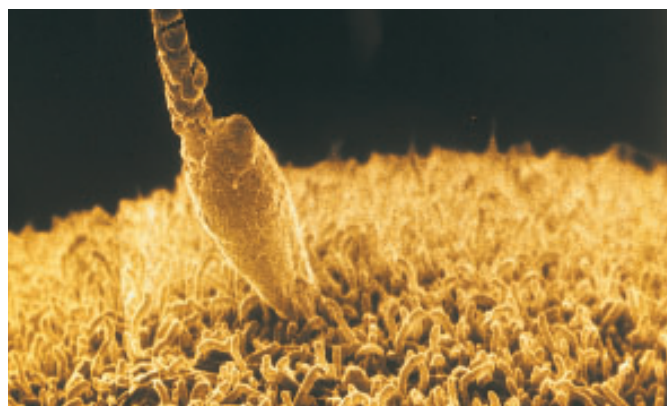


Figure 6
Egg cell being fertilized by sperm cell, 5000×

4. Provide examples of hereditary traits that are
 - (a) determined by genes
 - (b) influenced by the environment
5. Many single-cell organisms divide by a process called binary fission. One cell divides into two cells identical to each other and identical to the original cell. More complex organisms form specialized sex cells. When sex cells combine from two different organisms, they form a fertilized egg or zygote.
 - (a) Identify one advantage of binary fission as a means of reproduction.
 - (b) Identify and explain an advantage of reproduction by the union of sex cells from different individuals.
6. Explain why the duplication of genetic material is essential prior to division.

Skills












7. **Table 1** shows the events in a typical cell cycle. Draw and label a circle graph to represent the data.
8. A couple are expecting their third child. After the birth of two boys, they reason that the next child will be a girl.
 - (a) Determine the probability of having three boys in a row.
 - (b) Determine the probability that the next child will be a girl.

Table 1 Events in the Cell Cycle

Event	Time (h)
rapid growth	15
growth and DNA replication	20
preparation for division	10
mitosis	5

Cell Division

In this chapter

-  Exploration: Observing *Daphnia*
-  Investigation 17.1: Frequency of Cell Division
-  Mini Investigation: Cloning from a Plant Cutting
-  Explore an Issue: The Ethics of Stem Cell Research
-  Web Activity: Stem Cell Cord Blood
-  Investigation 17.2: Identification of a Cancer Cell
-  Mini Investigation: Gamete Formation in Grasshoppers
-  Investigation 17.3: Comparing Mitosis and Meiosis
-  Web Activity: Comparing Life Cycles of Plants
-  Web Activity: Dr. Renée Martin
-  Web Activity: Modelling Mitosis and Meiosis

All life depends on the ability to grow and reproduce. Both these processes involve cell division. Organisms that reproduce asexually produce offspring that are identical to the parents. Sexually reproducing organisms exchange genetic information, so that the offspring have a unique combination of traits. The genetic material determines the proteins that make up cells, which ultimately give rise to physical traits.

Daphnia (Figure 1, next page) is a truly remarkable animal. Females can produce offspring without a mate since they can produce eggs that require no fertilization. Upon development, these eggs become females, which in turn produce females, all of which are identical to each other and to the parent. Then, in response to some environmental cue, *Daphnia* begin producing eggs that develop as either males or females. The males and females produce sex cells. Sexual reproduction occurs when the sperm cells fertilize the egg cells, producing many offspring with a variety of traits. Asexual reproduction occurs when food is plentiful, while sexual reproduction is triggered during times of environmental stress.

All of the cells in *Daphnia* arise from one single cell. To develop into the complex organism in Figure 1, that single cell must divide many times. In this chapter, you will explore the events that occur during cell division in order to produce cells of the body and specialized cells involved in reproduction.



STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Make a list of the advantages of being multicellular.
2. Suggest possible advantages of reproducing
 - (a) asexually
 - (b) sexually
3. If 22 chromosomes are found in the muscle cell of a mouse, predict the number of chromosomes found in each cell of the following types:
 - (a) brain cell
 - (b) sperm cell
 - (c) fertilized egg cell
 Explain your predictions.



Career Connection:
Geneticist

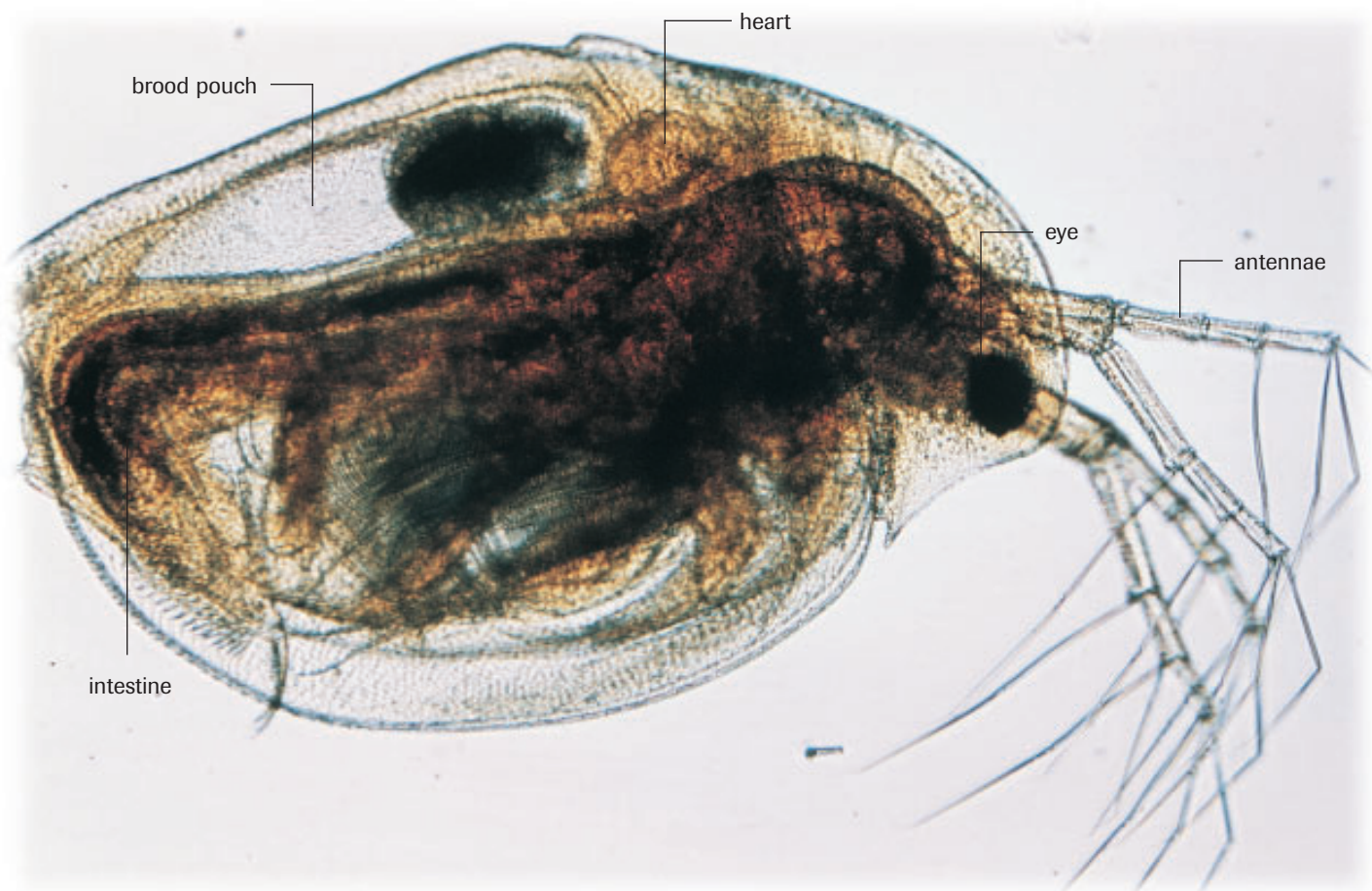


Figure 1

Daphnia is also known as a water flea, but it is a crustacean, not an insect.

► Exploration

Observing *Daphnia*

Materials: prepared slide of *Daphnia*, concave depression slide, glycerin, cover slip, *Daphnia* culture, medicine dropper, microscope, ice cubes, cotton swab

- If available, look at a prepared slide of *Daphnia*. Take note of the *Daphnia*'s general appearance and the location of certain features (e.g., eyes, antennae, heart) so that you will be able to identify them more easily in the *Daphnia* culture.
- Remove the prepared slide. Obtain the other materials. Using a cotton swab, smear some glycerin into the depression on the slide. Then, using a medicine dropper, place a small drop of *Daphnia* culture onto the glycerin. Prepare a wet mount by adding a cover slip. Examine the slide under low-power magnification. Pay attention to the movement and heart rate of the organism.
- Place the slide on an ice cube for 3 min, then dry the bottom of the slide with a paper towel and observe once again under low-power magnification.
 - (a) Why did you smear glycerin on the slide?
 - (b) Why did you put the slide on an ice cube?
 - (c) Make and label a scientific drawing of a *Daphnia*.
 - (d) Do you think that *Daphnia* are composed of many cells? Describe any features that you observe that demonstrate this fact.
 - (e) Try viewing the *Daphnia* under medium power. (*Hint:* You may have to adjust the diaphragm.) Draw what you see.

17.1 The Cell Cycle

Learning Tip

DNA, the cell's hereditary information, is found in the chromosomes of a cell. In eukaryotic cells (cells with a nucleus), the chromosomes are found in the nucleus. Review this information in Section 6.5 of this book.

All the estimated 100 trillion cells that make up your body arose from a single fertilized egg. As with the frog egg shown in **Figure 1**, this fertilized egg cell underwent a series of divisions that increased the number of cells, thus increasing the size and complexity of your body until eventually you reached your current size. Cell division also maintains a fully grown individual. All multi-cellular eukaryotic organisms grow in size and maintain the cells of their body (the somatic cells) by a sequence of events called the **cell cycle**.

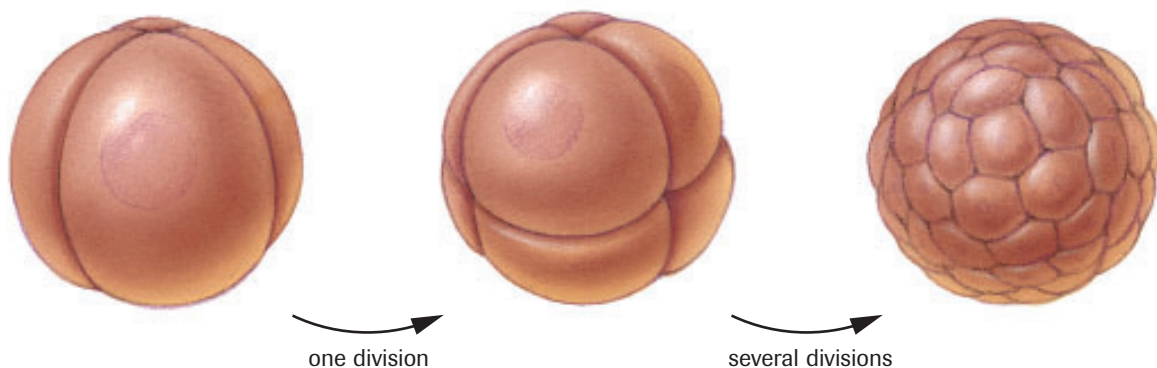


Figure 1

Early stages of cell division of a fertilized frog egg

cell cycle the sequence of stages through which a cell passes from one cell division to the next

mitosis (M) a type of cell division in which a daughter cell receives the same number of chromosomes as the parent cell

cytokinesis the division of cytoplasm

interphase the time interval between nuclear divisions when a cell increases in mass, roughly doubles the cytoplasmic components, and duplicates its chromosomes

The cell cycle is often described as taking place in phases (**Figure 2**, next page). However, the cycle is a continuous process and does not pause after each phase. During the division phase (**mitosis**, or **M**), the components of the cytoplasm and the components of the nucleus of the parent cell are divided to give rise to two identical daughter cells by two processes, mitosis and cytokinesis. Mitosis ensures the equal distribution of the nuclear contents. This process includes the duplication of chromosomes, so that each daughter cell ends up with the same number of chromosomes as the parent cell. **Cytokinesis** divides the cytoplasm and its constituent organelles of the parent cell roughly equally between the daughter cells.

For most cells, the nuclear division that occurs during mitosis marks only a small part of their cycle. The stage between division phases, called **interphase**, is marked by a period of rapid growth (gap 1, or G1), the duplication of chromosomes (synthesis, or S), another period of growth (gap 2, or G2), and preparation for further divisions. Cells carry out their particular functions during interphase.

Chromosome Structure

Before looking at the details of mitosis, you will need to know something about the structure of chromosomes. In animals such as humans, the DNA is divided among a number of chromosomes. Chromosomes contain both DNA and a number of proteins.

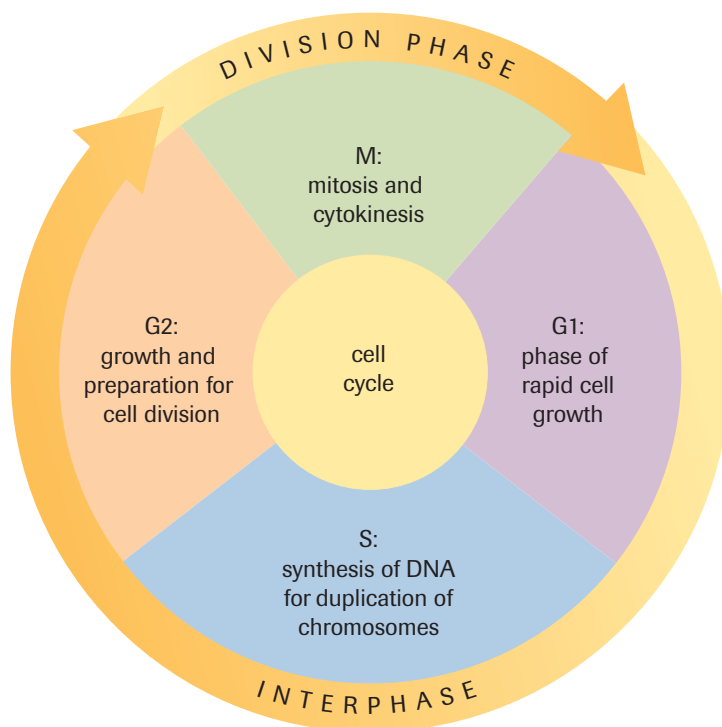


Figure 2

The cell cycle. The circle represents the entire life cycle of the cell, which can be divided into two major phases: interphase and the division phase. Most cells spend the majority of their time in interphase.

This combination of DNA and proteins is called **chromatin**. As the cell moves through the cell cycle, chromosomes may be either uncondensed or condensed. Uncondensed chromosomes are long, thin strands that cannot be seen under a light microscope. A condensed chromosome can be seen under a light microscope and may resemble the diagram in **Figure 3**. Condensed chromosomes may be either unduplicated or duplicated. In a duplicated chromosome, the original chromosome and its duplicate are attached to each other by a structure called the **centromere**. While attached to one another, the two chromosome duplicates are called **sister chromatids**. Since sister chromatids contain identical genetic information, the pair, attached at the centromere, is still considered to be one chromosome.

chromatin the complex of DNA and protein that make up chromosomes

centromere the structure that holds chromatids together

sister chromatids a chromosome and its duplicate, attached to one another by a centromere until separated during mitosis

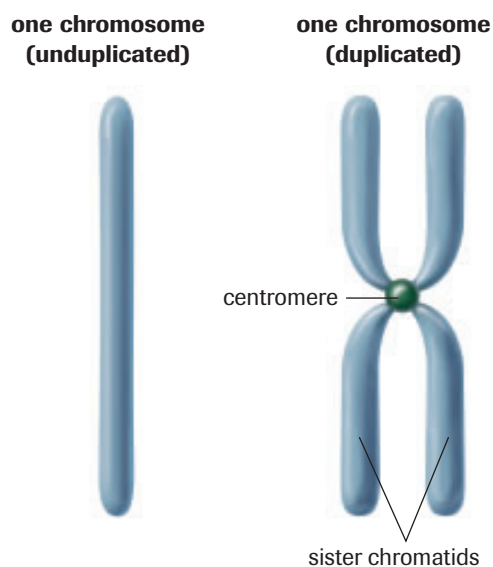


Figure 3

An unduplicated and a duplicated chromosome

Interphase

Cells spend most of their lives in interphase. In this phase of the cell cycle, cells are not actively dividing. Interphase includes the G₁, S, and G₂ phases of the cell cycle. Cells in interphase grow and undergo the various metabolic processes needed for their functioning during G₁, S, and G₂.

Chromosomes are uncondensed throughout interphase (**Figure 4**). During G₁, cells undergo a period of rapid growth, and the chromosomes are unduplicated. During the S phase, cells begin to prepare for division during interphase by duplicating its chromosomes. At the end of the S phase, all the chromosomes are therefore duplicated chromosomes. During G₂, the cell again grows and it completes the preparations for division (mitosis, or the M phase).

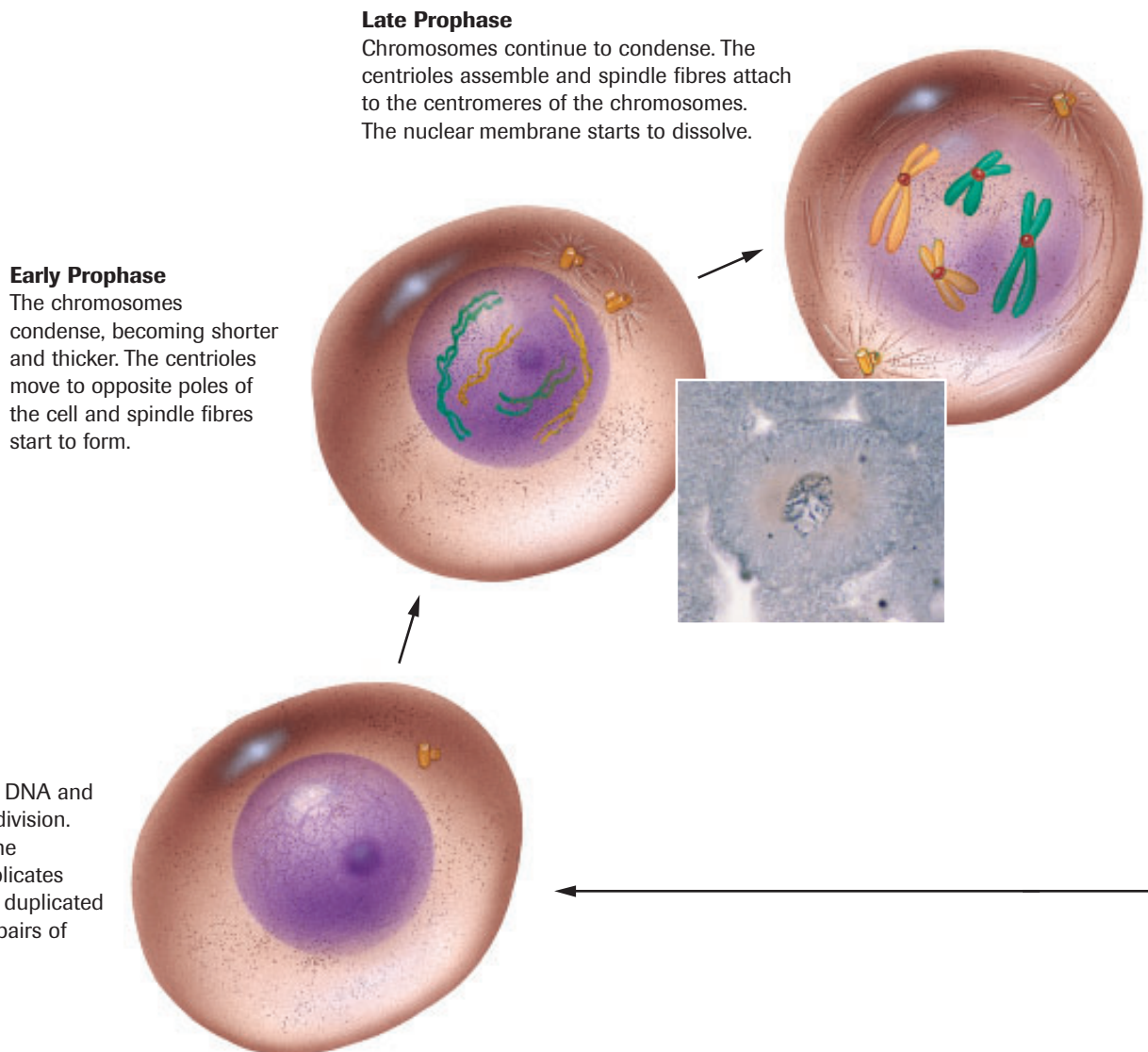


Figure 4 

Interphase and mitosis in an animal cell. Interphase includes the G₁, S, and G₂ phases of the cell cycle. Mitosis and cytokinesis occur during the M phase.

The Stages of Mitosis

Prophase

Prophase is the first phase of mitosis. The chromosomes in the nucleus become visible under a microscope as they shorten and thicken (**Figure 4**). In animal cells, a small body in the cytoplasm separates and its parts move to opposite poles of the cell as the chromosomes become visible. These tiny structures, called **centrioles**, provide attachment for the **spindle fibres**, which serve as guide wires for the attachment and movement of the chromosomes during cell division. Collectively, the centrioles and spindle fibres make up the spindle apparatus. Most plant cells do not have centrioles, but spindle fibres still form and serve a similar purpose. The centromere joining the two chromatids helps anchor the chromosomes to the spindle fibres. When viewed under a microscope during prophase, the nuclear membrane appears to fade; in effect, it is dissolving to allow the separation of chromosomes and cell organelles.

centriole small protein body found in the cytoplasm of animal cells that provides attachment for spindle fibres during cell division

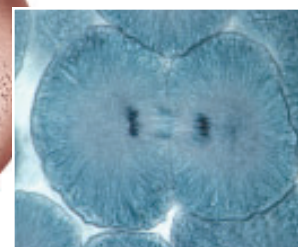
spindle fibre protein structure that guides chromosomes during cell division

Metaphase

Chromosomes line up at the equatorial plate. The nuclear membrane completely dissolves.

Anaphase

The centromeres divide and the resulting chromosomes, formerly chromatids, move to opposite poles of the cell. An identical set of chromosomes moves to each pole.



Telophase

Chromosomes lengthen again, the spindle fibres dissolve, and a nuclear membrane forms around the chromosomes. In humans, each new nucleus contains 46 unique chromosomes.

+ EXTENSION

Mitosis and Cell Division in Plants and Animals

This Audio Clip highlights the observable differences between plant and animal cell mitosis and cytokinesis.

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Metaphase

The second phase of mitosis is metaphase. Chromosomes composed of sister chromatids move toward the centre of the cell. This centre area is called the equatorial plate, because, like the equator of Earth, it is midway between the poles of the cell. The chromosomes appear as dark, thick filamentous structures that are attached to the spindle fibres. Even though they are most visible at this stage, it is still very difficult to count the number of chromosomes in most cells because the chromosomes are entangled. Chromatids can become intertwined during metaphase.

Anaphase

Anaphase is the third phase of mitosis. The centromeres divide and the sister chromatids, now referred to as chromosomes, move to opposite poles of the cell. If mitosis proceeds correctly, the same number and type of chromosomes will be found at each pole. Occasionally, segments of the chromatids will break apart, and may reattach, in anaphase.

Telophase

The last phase of mitosis is telophase. The chromosomes reach the opposite poles of the cell and begin to lengthen. The spindle fibres dissolve and a nuclear membrane forms around each mass of chromatin. Telophase is followed by cytokinesis, the division of the cytoplasm.

Cytokinesis

Once the chromosomes have moved to opposite poles, the cytoplasm begins to divide. Cytokinesis appears to be quite distinct from nuclear division. In an animal cell, a furrow develops, pinching off the cell into two parts. This is the end of cell division. In plant cells, the separation is accomplished by a cell plate that forms between the two chromatin masses. The cell plate will develop into a new cell wall, eventually sealing off the contents of the new cells from each other.

Situation A

Cells are grown in culture.



Cells are frozen in liquid nitrogen after 20 divisions.



After cells thaw, they divide 30 more times.



Situation B



Cells are frozen in liquid nitrogen after 40 divisions.



After cells thaw, they divide 10 more times.



Total: 50 cell divisions

Figure 5

Cell division appears to be controlled by a biological clock.

Practice

1. List the stages of mitosis. Briefly describe what occurs in each stage. To help in your description, sketch the sequence of events that occurs in an animal cell. Include labels for different structures.
2. A cell with 10 chromosomes undergoes mitosis. Indicate how many chromosomes would be expected in each of the daughter cells.

A Cell Clock

How old can cells become? If cells continue to undergo mitosis, could an organism stay eternally young and live forever? Research on cultured cells (cells grown in a nutrient medium) indicates that a biological clock may regulate the number of cell divisions available to cells. When immature heart cells maintained in tissue culture were frozen, they revealed an internal memory of the number of cell divisions they had undergone. If a cell had undergone twenty divisions before freezing, the cell completed another thirty divisions once it thawed, then died. When a cell was frozen after ten divisions, it completed another forty divisions after thawing and then died. Cells always completed a total of fifty divisions no matter how long the freezing or at what stage the cell division was suspended (**Figure 5**).

Not all cells of the body have the same ability to undergo mitosis. Age is one reason cells stop dividing. However, division is usually stopped by cell specialization. Relatively unspecialized cells, such as skin cells and the cells that line the digestive tract, reproduce more often than do the more specialized muscle cells, nerve cells, and secretory cells. Only two cell types in the human body divide endlessly: the sperm-producing cells, called spermatogonia, and the cells of a cancerous tumour. Males are capable of producing as many as one billion sperm cells a day from the onset of puberty well into old age. However, once the sperm cells are formed, they lose the ability to divide further. Cancer cells divide at such an accelerated rate that the genes cannot regulate the proliferation and cannot direct the cells toward specialization.

It would appear that the more specialized a cell is, the less able it is to undergo mitosis. The fertilized egg cell is not a specialized cell; differentiation begins to occur only after its third division, which results in eight cells. Interestingly, it is at the point where differentiation begins that the biological clock within the cell is turned on.

+ EXTENSION



Cancer and Metastasis

Cells that divide uncontrollably can become cancer. This animation shows how cancer cells can spread from one part of the body to another.

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INVESTIGATION 17.1 Introduction

Frequency of Cell Division

In this activity, you will view and compare cells from onion cells and from a whitefish blastula in various stages of mitosis. Because slides are used, the cell divisions you will be viewing are frozen in time. Therefore, it will not be possible for you to watch a single cell progress through the stages of mitosis. Based on your observations, you will determine the frequency of cell division

Report Checklist

- | | | |
|--|---|---|
| <input checked="" type="radio"/> Purpose | <input type="radio"/> Design | <input checked="" type="radio"/> Analysis |
| <input type="radio"/> Problem | <input type="radio"/> Materials | <input checked="" type="radio"/> Evaluation |
| <input type="radio"/> Hypothesis | <input type="radio"/> Procedure | <input checked="" type="radio"/> Synthesis |
| <input type="radio"/> Prediction | <input checked="" type="radio"/> Evidence | |

and construct a clock representing the division cycle, given the time taken to complete one cycle of mitosis. In a table, you will record the number of cells in each stage of mitosis.

To perform this investigation, turn to page 587.

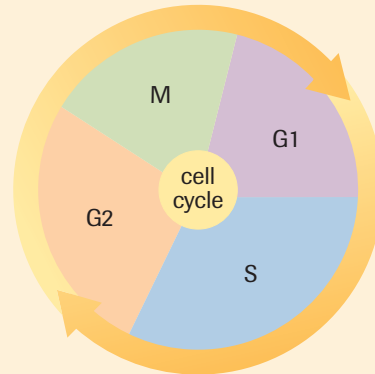
SUMMARY The Cell Cycle

- Cell division produces new cells for cell growth and for the replacement of worn-out cells in the body.
- Cell division involves a series of steps that produce two genetically identical daughter cells. Two divisions occur during cell division: nuclear division (mitosis) and cytoplasmic division (cytokinesis).
- During interphase, genetic material is replicated.
- Cells seem able to divide only a finite number of times.
- Cells lose the ability to divide as they specialize.

► Section 17.1 Questions

- During interphase, what event must occur for the cell to be capable of undergoing future divisions?
- Using a dictionary, look up the meaning of the prefixes used in the stages of mitosis: *pro-*, *meta-*, *ana-*, and *telo-*. Why would they be used in the naming of the phases of mitosis?
- Compare and contrast the structure of the daughter cells with that of the original parent cell.
- Describe the structure and explain the function of the spindle fibres.
- What is the significance of cytokinesis? Speculate what would happen if cytokinesis did not occur.
- When a cell has reached its maximum size, what two alternatives does it have? When does the cell carry out one alternative over the other?
- What would happen if you ingested a drug that prevented mitosis? What if it only prevented spindle fibre formation?
- A cell from a tissue culture has 38 chromosomes. After mitosis and cytokinesis, one daughter cell has 39 chromosomes and the other has 37. What might have occurred to cause the abnormal chromosome numbers?
- Suppose that during mitosis, both sister chromatids moved to the same pole, resulting in daughter cells with a different number of chromosomes than the parent cell. How might this abnormality affect cell structure, cell function, or both?
- Explain the concept of the cell clock.
- Suggest reasons why skin cells, blood cells, and the cells that line the digestive tract reproduce more often than other types of cells such as muscle cells. If some of these cells were to become cancerous, how might a chemical therapy to stop those cells from reproducing work?
- (a) Describe the differences between the two cell cycles in **Figure 6**.
(b) Which cell cycle do you believe would represent a cell of an embryo and which would represent an unspecialized cell in an adult? Give your reasons.
- List areas of the body where you think cell division is most rapid. Also, indicate the comparative level of specialization of the cells in each area. Explain your predictions.
- It is believed that weed killers like 2,4-D and 2,4,5-T may work by stimulating cell division. Why would the stimulation of cell division make these chemicals effective weed killers?
- At one time, blood was transfused only from younger individuals to the elderly. It was believed that younger blood would provide the elderly with more energy. Do older people actually have older blood cells? Support your answer.
- X-rays and other forms of radiation break chromosomes apart. Physicians and dentists will not X-ray pregnant women. Even women who are not pregnant wear a lead apron when being X-rayed near the reproductive organs. The apron blocks the passage of X-rays. Why is it undesirable to X-ray the reproductive organs? Why is it especially undesirable to X-ray pregnant women?
- Scientists have developed techniques aimed at getting highly-specialized cells to act as if they are immature cells that have not yet become specialized. Why would scientists want to be able to get a mature nerve cell to respond like a cell that hasn't undergone specialization?

Cell Cycle for Cell A: 36 h



Cell Cycle for Cell B: 25 h

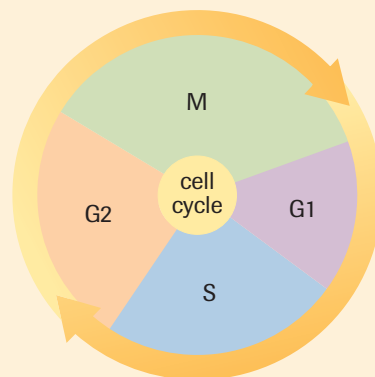


Figure 6

Applications of the Cell Cycle

17.2

Scientists continue to study the cell cycle and to gain a deeper understanding of the mechanisms and the role of the process. As more is learned about the cell cycle, we have been able to apply this knowledge to many human needs. There are various perspectives on the costs and benefits of these new technologies, and when they are appropriate to use.

Cloning

Cloning is the process of forming identical offspring from a single cell or tissue in the parent organ. A clone originates from a single parent cell, and both the clone and parent have identical (or nearly identical) nuclear DNA. Although some clones show accidental changes in genetic information, cloning does not result in the variation of traits that would occur with the combination of male and female sex cells. Cloning is therefore considered a form of asexual reproduction. In fact, clones occur naturally. Some species, such as hydra (**Figure 1 (a)**) reproduce by undergoing mitosis to produce buds with identical DNA to the larger parent cell. The smaller plantlets on a runner of a strawberry plant are identical clones of the larger parent plant (**Figure 1 (b)**). In animals, offspring with an identical genetic makeup are sometimes produced when a single fertilized egg undergoes mitosis and the resulting early embryo (called a zygote) then splits in two (**Figure 1 (c)**). This results in identical twins. They are also called monozygotic twins, since they formed from a single zygote. Fraternal twins are formed when two different eggs are fertilized separately. They are also known as dizygotic twins. Fraternal twins, therefore, are no more genetically similar than are non-twin siblings (**Figure 1 (d)**).

DID YOU KNOW?

Multiple Births

It has been estimated that 1 in 85 births will produce twins, 1 in 7500 will produce triplets, 1 in 650 000 will produce quadruplets, and 1 in 57 000 000 will produce quintuplets.

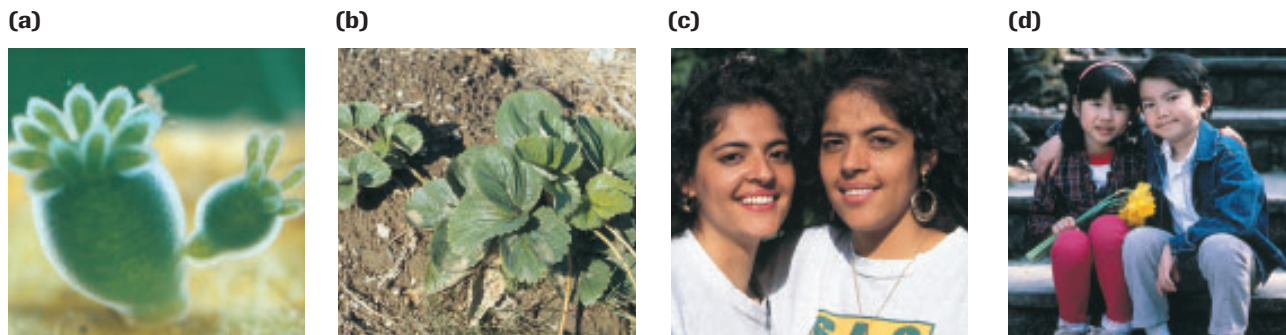


Figure 1

- (a)** Hydra reproduce asexually by budding. The buds break off to form separate, genetically identical organisms.
- (b)** The strawberry plant can reproduce asexually by forming genetically identical plantlets on runners.
- (c)** Identical twins originate from a single fertilized egg that undergoes mitosis to produce an early embryo which then splits into two, producing two genetically identical individuals.
- (d)** Development of fraternal twins does not involve the splitting of a fertilized egg. Instead, fraternal twins develop from two independent fertilization events, such as occurs when a mother has two eggs in her uterus that are fertilized by two different sperm cells. Each fertilized egg then develops independently.

▶ mini Investigation

Cloning from a Plant Cutting

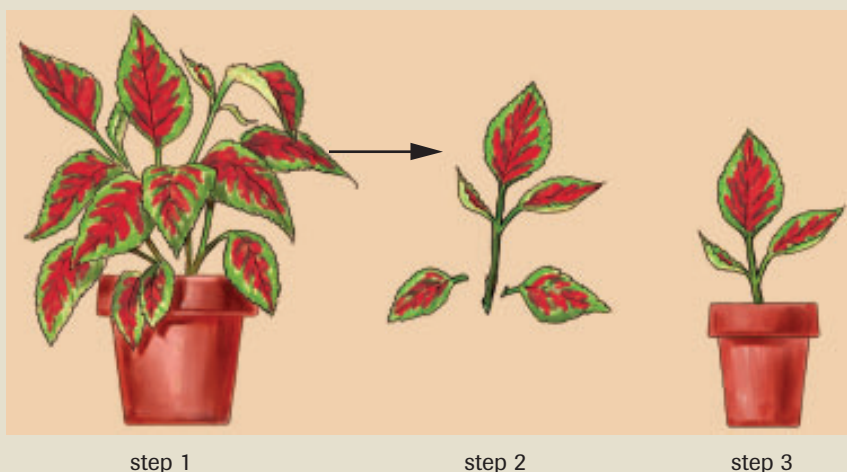
In some plants, asexual reproduction is accomplished naturally when a portion of the plant, such as a stem or leaf, breaks off and develops roots at the base of the broken portion. It is possible for the broken part to become a new plant. This activity is an example of artificial propagation.

Materials: coleus plant, scissors, goggles, gloves, fungicide, flower pot, potting soil, apron



The fungicide is poisonous. Review the MSDS before beginning this investigation. Any spills on the skin, in the eyes, or on clothing should be washed immediately with cold water. Report any spills to your teacher.

- Perform the following steps as shown in **Figure 2**.
 1. Using scissors, carefully cut off the tips of three coleus stems. Cut on an angle. Include several leaves on each stem.
 2. Remove a few leaves from the bottom. Put on splash goggles, and wear gloves and/or use tongs to immerse the stem in fungicide.
 3. Plant the cuttings in soil.
- Record each cutting's initial height and number of leaves. Take these measurements every week for two months.
- Describe the new plants each time.
 - (a) What evidence suggests that coleus can regenerate parts of the plant that were lost?
 - (b) Without removing the plant from the pot, how can you demonstrate that the roots from the cutting are growing?



step 1

step 2

step 3

Figure 2

Plant Cloning Technology

In 1958, Fredrick Stewart created great excitement in the scientific world when he revealed that he had produced a plant from a single carrot cell (**Figure 3**). Today, this technique



Figure 3

Fredrick Stewart was able to grow a clone from a single cell of a carrot plant. This allowed production of many identical individuals from a sexually reproducing species. This was the first application of knowledge of mitosis in generating clones.

is commonly called cloning. Many commercially important plant species, including orchids, are now produced from clones. Unlike plants that arise from sexual reproduction, cloned plants are identical to their parents. This allows production of strains of plants with predictable characteristics. Not all plant species can be cloned, however. Carrots, ferns, tobacco, petunias, and lettuce respond well to cloning, but the grass and legume families do not. Scientists continue to investigate these differences.

Each cell in the cloned plant contains the complete complement of chromosomes from the parent. As the new plant develops, it undergoes mitosis to increase in size. Some cells then specialize (differentiate) and form roots, stems, or leaves, until a complete plant is formed.

Animal Cloning Technology

While plant cloning experiments were being conducted, Robert Briggs and Thomas King were busy investigating nuclear transplants in frogs. Working with the common grass frog, the scientists extracted the nucleus from an unfertilized egg cell by inserting a fine glass tube, or micropipette, into the cytoplasm and sucking out the nucleus (**Figure 4**). A cell without a nucleus is referred to as **enucleated**.

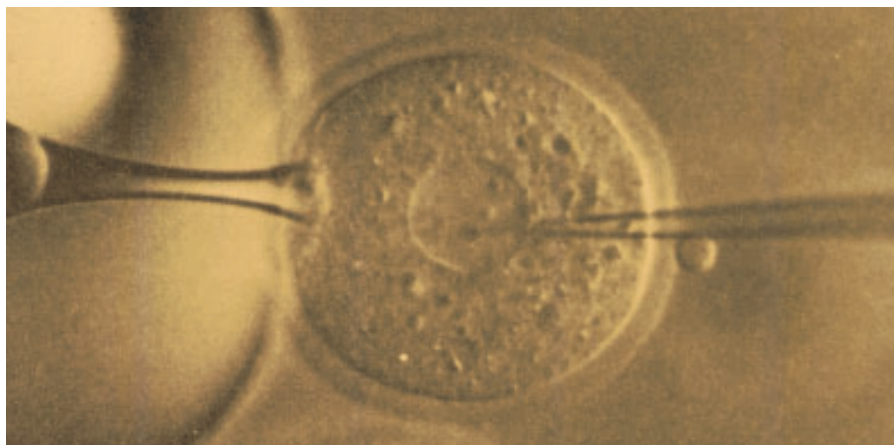


Figure 4

A small glass tube, called a micropipette, is used to remove the nucleus from a cell and later introduce a new nucleus.

Next, the nucleus of a cell from a frog embryo in the blastula stage of development was removed and inserted into the enucleated cell (**Figure 5**). The egg cell with the transplanted nucleus began to divide much like any normal fertilized egg cell. In later trials, the cell with the transplanted nucleus occasionally grew into an adult frog. The adult frogs displayed the characteristics from the transplanted nucleus. Careful analysis proved that the adults were clones of the frog that donated the nucleus.

However, different results were obtained when the nucleus was taken from cells at later stages of development. For example, the nucleus from cells in a later stage, called the gastrula stage, did not bring the enucleated egg from the single-cell stage to the adult. If mitosis occurred at all, it did not progress as far as it did in eggs that received a blastula nucleus. The difference is that the nucleus of a cell in the gastrula stage of development, unlike a cell in the earlier blastula stage, has specialized. As cells begin to specialize, they become less able to undergo mitosis.

enucleated the condition where a cell does not contain a nucleus

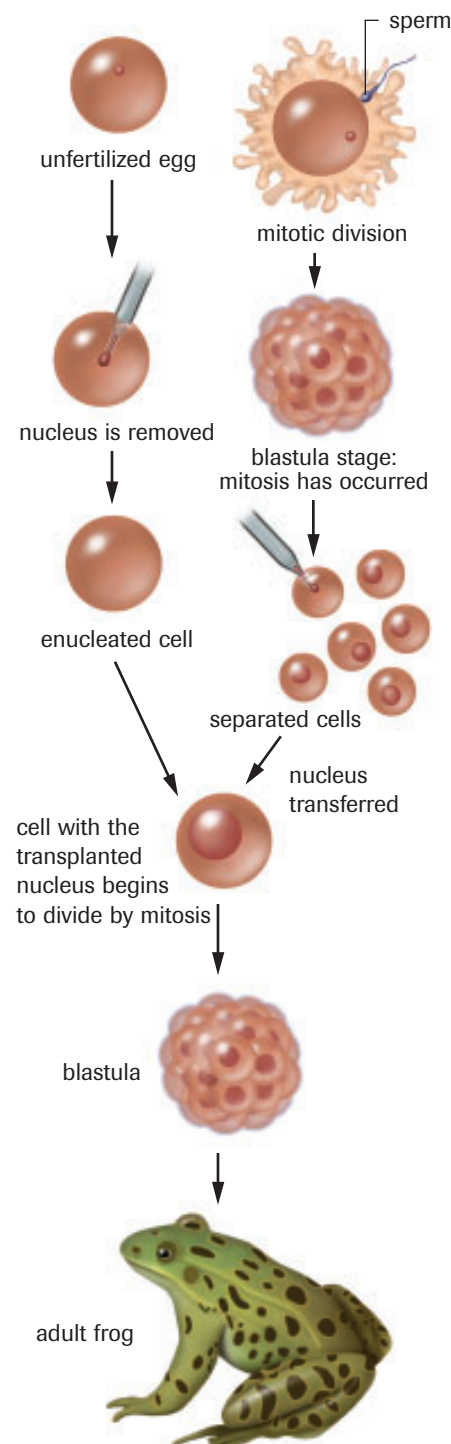


Figure 5

Cloning a common grass frog using embryo splitting

Cloning from adult mammalian cells has proved even more difficult, since they tend to be highly specialized. Until recently, the only way to get clones was by splitting off cells from a developing embryo (**Figure 6**). However, cells beyond the eight-cell stage of development seem to be unable to stimulate cell division.

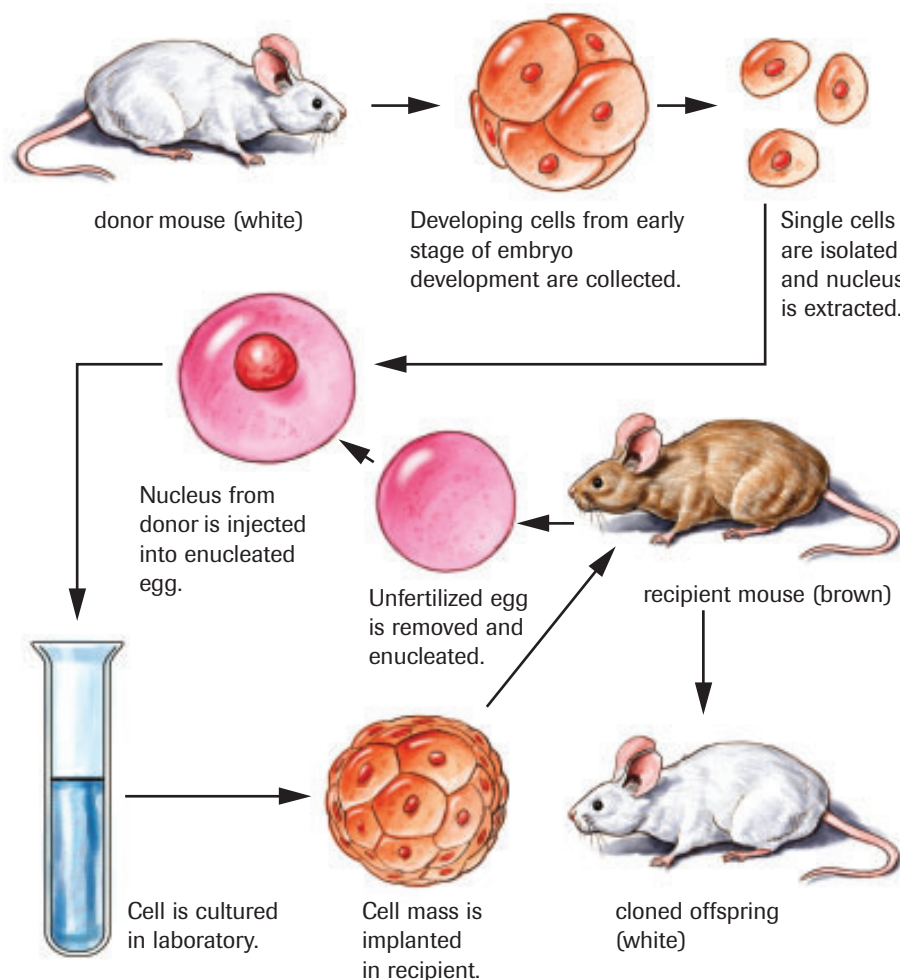


Figure 6
Cloning a mammal using embryo splitting



Figure 7
Dolly could claim three different sheep as mothers. The genetic mother died before Dolly was born.

The long-held scientific belief that adult cells cannot be used to clone animals was disproved with the appearance of a sheep named Dolly. Dr. Ian Wilmut, of the Rosalind Institute in Scotland, extracted the nucleus from an udder cell of an adult Finn Dorsett sheep and placed the nucleus into the enucleated egg cell from a Poll Dorsett sheep. The egg was allowed to develop in a Petri dish until an early embryo stage was reached. Then this embryo was placed into the womb of a third sheep, a Scottish Blackface. Her genetic information was shown to be identical to that of the Finn Dorsett adult; Dolly was a clone (**Figure 7**).

Medical experimentation and research could potentially benefit from the availability of cloned animals. For example, experiments on the effectiveness of a drug are often difficult to interpret because of the genetic variation among the individuals tested. If all the test subjects were genetically identical, clearer results could be obtained. In agriculture, the strongest livestock could be cloned, decreasing farmers' losses due to disease, and thereby increasing yield. However, many people have moral and ethical problems with this technology and worry about the impact on society.

Practice

1. List the steps involved in cloning animals from nuclei taken from the blastula stage of development.
2. Why are identical twins often called “nature’s clones”?
3. Do all the cells of your body divide at the same rate? Explain.
4. What is an enucleated cell?

+ EXTENSION



Stem Cells

This *NOVA* video asks what are stem cells and how do we find a balance between hope for cures and respect for life.

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EXPLORE an issue

The Ethics of Stem Cell Research

A **stem cell** is a cell from which any other type of cell can arise (stem). Upon receiving the appropriate signals, stem cells differentiate into specialized cells with a particular function, such as heart muscle cells. Since a stem cell has not differentiated, it can undergo many cell divisions. Fertilized eggs and early embryos are composed entirely of stem cells. Plants retain many stem cells throughout life, in the growing tips of roots and shoots. Some adult animals also retain many stem cells, such as in salamanders that can grow a lost tail. In contrast, the adult human body has very few stem cells. Stem cells are found in the adult human body in bone marrow, fat, blood, and even in hair follicles. The richest source of non-embryonic stem cells is umbilical cord blood.

Stem cells have the potential of having enormous medical benefits. Since stem cells can potentially give rise to any other type of cell, they may be able to help people whose cells are not able to function properly. For example, stem cells could be used to replace faulty insulin-producing cells in the pancreas of diabetics or faulty neurotransmitter-producing cells in the brains of people with Parkinson disease.

Some people do not agree with the use of stem cells on ethical grounds. Scientists still do not fully understand how a single, unspecialized cell becomes a complex organism with many specialized cells. Some people worry that scientists may

Issue Checklist

- | | | |
|--------------|------------|--------------|
| ● Issue | ● Design | ● Analysis |
| ● Resolution | ● Evidence | ● Evaluation |

use human embryos to answer these questions. Others believe that any cell that can potentially give rise to a human being should not be used for research or therapy.

- In small groups, conduct background research on this rapidly changing field of research using newspapers, periodicals, CD-ROMs, and the Internet. Outline how the issue is changing and any new issues that are emerging. Prepare a bibliography and make notes as you work.

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- Based on your background research, describe one ethical issue related to the use of stem cells in research or therapy.
- For the issue you have stated, write a statement that describes one viewpoint. For example, you might state, “Withholding a potential cure because it uses stem cells is unethical, because it causes people with a medical condition to suffer.”
- Decide whether you agree or disagree with the statement. If necessary, conduct additional research to find evidence to support or refute your viewpoint.
- Write a position paper. Be prepared to defend your group’s position to your classmates.

WWW WEB Activity

Web Quest—Stem Cell Cord Blood

Research into stem cell cord blood has provided major steps forward in scientific understanding. It is becoming commonplace for parents to save the blood from their newborn’s umbilical cord and to bank it in case of future medical needs. The issue is no longer whether or not banking the cord blood is acceptable, but rather the argument between the use of private or public stem cell cord blood banks. This Web Quest asks you to develop a supported position on this issue and create a presentation that can be given to your class.

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Stem Cells Update

This *NOVA* video discusses a new technique for creating stem cells that may ease ethical concerns.

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telomere the cap at the end of a chromosome

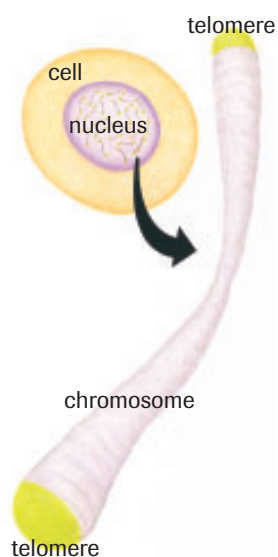


Figure 8
Telomeres are end caps of chromosomes. An enzyme, called telomerase, acts on the telomere causing changes in length.

Mitosis and Telomeres

Telomeres are caps at the ends of chromosomes (**Figure 8**). Scientists have determined that telomeres reduce in length each time a cell goes through the cell cycle and divides. Telomeres might have a role in cell aging and in the behaviour of cancer cells.

In 1984, Carol Greider and Elizabeth Blackburn set out to find the enzyme that affected the length of the telomere. Not only did they find the enzyme, but they also discovered much about how it works. Dr. Blackburn demonstrated a connection between telomerase and aging. Yeast cells that lack the enzyme telomerase undergo telomere shortening and eventually die. Other researchers working in Scotland found that as human cells age, telomere length shortens. The length of the chromosomes of a 70-year-old human is much shorter than that of a child. As we saw in Section 17.1, normal cells pass through the cell cycle only a finite number of times. Once a cell can no longer undergo mitosis, cell death occurs. Telomeres length serves as a molecular “clock” for cellular aging.

What impact does telomere length have on cloning technology? The answer is not yet clear. Since Dolly was cloned from the cells of a six-year-old sheep, she began life with shorter telomeres than would a non-cloned sheep. Dolly developed arthritis at an early age and died of lung disease in February of 2003 at only six years of age—half the normal life expectancy of a sheep. These events may be linked to telomere length. However, some cloned animals appear to have longer telomeres, as if they were younger.

In the human body, cells generally undergo mitosis only 50 to 100 times during their lifespan. Cancer cells, however, never seem to lose their ability to divide, and their telomere length is also maintained. Telomerase is also not present in most normal cells. A group working at McMaster University under the direction of Calvin Harley was the first to show that telomerase is reactivated in human cancer cells. This allows cancer cells to maintain telomere length and, therefore, their ability to divide (**Figure 9**). Dr. Harley is now working with a pharmaceutical company to develop a drug that can block telomerase action. They hope that decreasing telomerase activity will slow cell division of the cancer cells, but have little impact on normal cells.

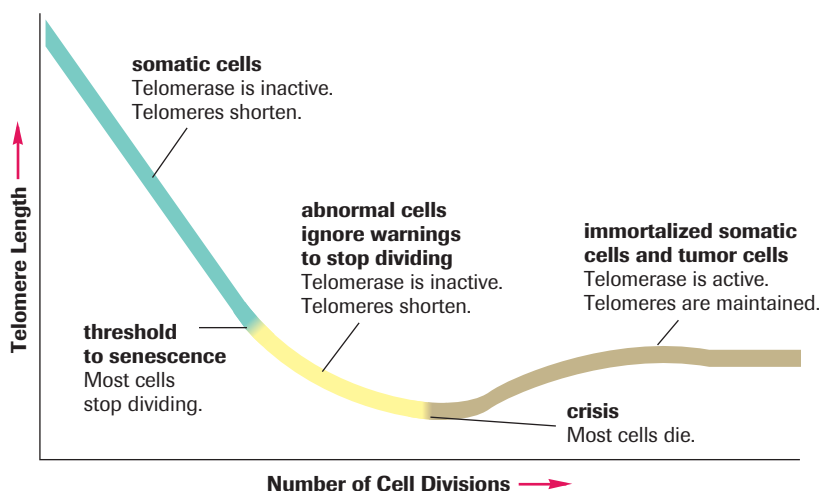


Figure 9
The activity of telomerase in normal cells (turquoise line) decreases as the cell ages. Eventually, the cells reach the point where damage to the chromosomes will result if the telomeres become any shorter. At this point, normal cells stop dividing and die. Abnormal cells continue to divide (yellow line). Cancer cells (brown line) reactivate telomerase and so are able to continue mitosis.

**INVESTIGATION 17.2 Introduction****Report Checklist****Identification of a Cancer Cell**

Cancer cells have unique features that can be used to distinguish them from non-cancerous cells. These differences can be used by medical professionals as a means of detecting cancer, often in earlier, easy-to-treat stages by technologies such as X-rays, infrared photography, and cell biopsies. Some of these differences can be viewed using a light microscope. What are these differences? Do they relate to the ability of these cells to continue undergoing mitosis?

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| <input type="radio"/> Hypothesis | <input type="radio"/> Procedure | <input checked="" type="radio"/> Synthesis |
| <input type="radio"/> Prediction | <input checked="" type="radio"/> Evidence | |

In this investigation, you will examine stained slides of cancerous and non-cancerous cells under a light microscope to observe some differences between these cell types.

To perform this investigation, turn to page 589.

SUMMARY**Applications of the Cell Cycle**

- Cloning is the process of forming identical offspring from a single cell or tissue.
- Cloning permits the production of offspring with characteristics identical to those of the parent.
- Some plants and animals naturally clone themselves (reproduce asexually).
- Technologies have been developed to clone both plants and animals. Further development of cloning technology relies on increased understanding of cell processes such as mitosis.

Section 17.2 Questions

1. Describe how nuclear transplants are used to clone frogs.
2. Dolly was not the first cloned animal, nor was she the first mammal clone. What made her cloning so special?
3. Explain why male animals would no longer be needed if cloning became the accepted method of reproduction.
4. If the nucleus is extracted from an adult animal cell and placed into an enucleated egg, how would it be possible to distinguish the cloned individual from the original?
5. Make a list of benefits and potential problems associated with cloning farm animals.
6. Speculate on the potential benefits and problems associated with cloning humans.
7. Research the nature versus nurture debate and the evidence provided by studies of twins. Find out about some psychological conditions that have both a genetic and an environmental component. What are the advantages and disadvantages of each approach? Think about the social, moral, and ethical implications of each viewpoint.

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17.3 Meiosis

meiosis two-stage cell division in which the chromosome number of the parental cell is reduced by half

haploid refers to the number of chromosomes in a gamete

diploid refers to twice the number of chromosomes in a gamete

homologous chromosomes paired chromosomes similar in shape, size, gene arrangement, and gene information

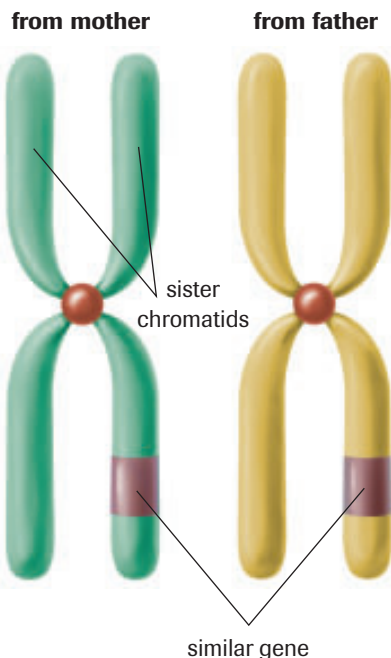


Figure 1
Homologous chromosomes

tetrad a pair of homologous chromosomes, each with two chromatids

synapsis the pairing of homologous chromosomes

crossing over the exchange of genetic material between two homologous chromosomes

Meiosis is the type of cell division involved in the formation of sex cells, or gametes. In humans, this takes place in the testes and ovaries. Meiosis involves two stages of cell division that have some similarities to the phases in mitosis. In mitosis, the chromosome number of the daughter cells is the same as in the parent cell. In meiosis, the chromosome number of the daughter cells is half that of the parent cell. A human cell containing 46 chromosomes will undergo meiosis and produce gametes that have 23 chromosomes. Each gamete will contain both the same number and the same kind of chromosomes. The number of chromosomes in a gamete is called the **haploid** chromosome number, or n ; the number of chromosomes in all other cells having a nucleus is twice the haploid number and is called the **diploid** number, or $2n$. In humans, the haploid chromosome number is 23 and the diploid chromosome number is 46.

Offspring carry genetic information from each of the parents. This explains why you might have your father's eyes but your mother's hair. Although you may look more like one parent than another, you receive genetic information from each parent. For example, your father gives you a chromosome with genes that code for eye colour, but so does your mother. Each of the 23 chromosomes that you receive from your biological father is matched by 23 chromosomes from your biological mother, so that each parent gives you half of your genetic information. The paired chromosomes are called **homologous chromosomes** because they are similar in shape, size, and gene arrangement (**Figure 1**). The genes in homologous chromosomes deal with the same traits. Each cell in your body, except the sex cells, contains 23 pairs of homologous chromosomes, or 46 chromosomes in total. The 23rd pair of chromosomes, which determine sex in mammals, are called the X and Y chromosomes and are only partially homologous. Males receive an X and a Y chromosome and females receive two X chromosomes. You will learn more about these chromosomes later in this chapter and in Chapter 22.

During fertilization, a haploid ($n = 23$) sperm cell unites with a haploid ($n = 23$) egg cell to produce a diploid ($2n = 46$) zygote. The fusion of male and female gametes restores the diploid chromosome number in the zygote. The zygote will begin dividing by mitosis and will eventually become a multicellular human baby.

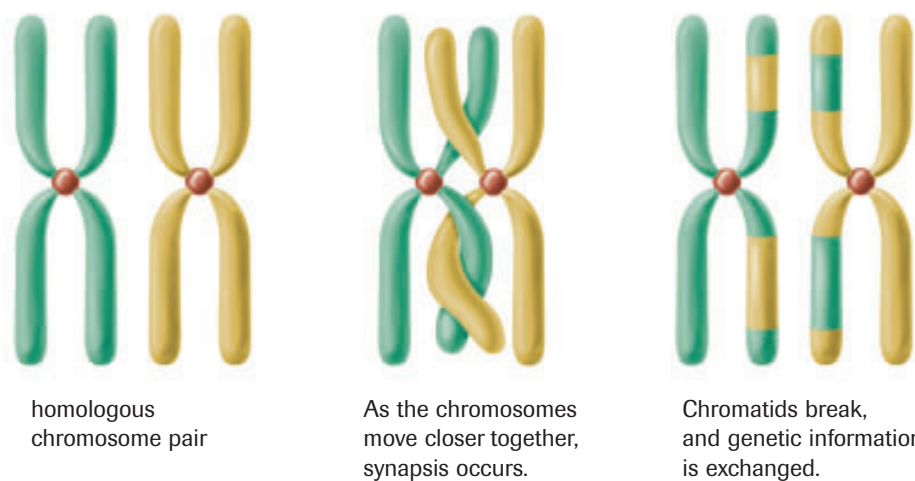
Stages of Meiosis

Meiosis involves two nuclear divisions that produce four haploid cells. Meiosis I is often called reduction division because the diploid, or $2n$, chromosome number is reduced to the haploid, or n , chromosome number. The second phase, meiosis II, is marked by a separation of the two chromatids. The phases used to describe the events of mitosis can also be used to describe meiosis. As with mitosis, DNA synthesis occurs prior to the cell division phase.

Meiosis I

During prophase I, the nuclear membrane begins to dissolve, the centriole splits and its parts move to opposite poles within the cell, and spindle fibres are formed. The chromosomes come together in homologous pairs. Each chromosome of the pair is a homologue and is composed of a pair of sister chromatids. The whole structure is then referred to as a **tetrad** because each pair is composed of four chromatids.

This process is referred to as **synapsis**. As the chromosomes synapse, the chromatids often intertwine. Sometimes the intertwined chromatids from different homologues break and exchange segments in a process called **crossing over** (**Figure 2**, next page). Crossing over permits the exchange of genetic material between homologous pairs of chromosomes.

**Figure 2**

Crossing over occurs between homologous pairs of chromosomes during prophase I of meiosis.

Metaphase I follows prophase I (**Figure 3**). The homologous chromosomes attach themselves to the spindle fibres and line up along the equatorial plate.

During anaphase I, the homologous chromosomes move toward opposite poles. The process is known as segregation. At this point of meiosis, reduction division occurs. One member of each homologous pair will be found in each of the new cells. Each chromosome consists of two sister chromatids.

During telophase I, a membrane begins to form around each nucleus. However, unlike in mitosis, the chromosomes in the two nuclei are not identical because each of the daughter nuclei contains one member of the homologous chromosome pair. Although homologous chromosomes are similar, they are not identical. They carry genes for the same traits (for example, eye colour), but those genes may differ (for example, coding for brown eyes or coding for blue eyes). The cells are now ready to begin the second stage of meiosis.

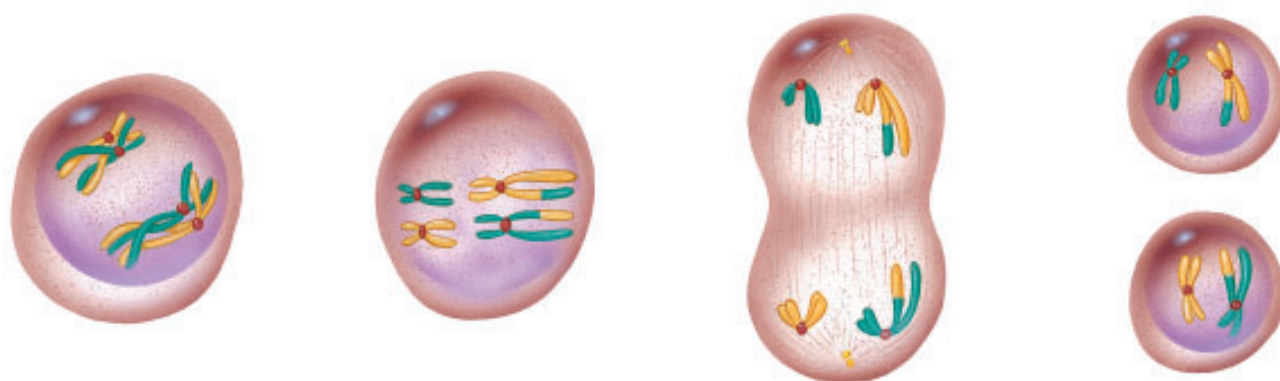
+ EXTENSION



Crossing Over

This Audio Clip will discuss the timing of crossing over and the benefit that a species derives from this process.

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prophase I

The replicated chromosomes condense. Homologous chromosomes come together in synapsis and crossing over occurs. Chromosomes attach to the spindle.

metaphase I

Chromosomes line up at the equatorial plate.

anaphase I

Each chromosome separates from its homologue. They move to opposite poles of the cell.

telophase I

The nucleus completes its division. The chromosomes are still composed of sister chromatids. The cytoplasm divides after telophase.

Figure 3

During meiosis I, homologous chromosomes are segregated.

Meiosis II

Meiosis II occurs at approximately the same time in each of the haploid daughter cells. However, for simplicity, consider the events in only one of the cells. (In **Figure 4**, both cells from meiosis I are shown). During meiosis II, pairs of chromatids will separate and move to opposite poles. Note that, unlike with mitosis and meiosis I, there is no replication of chromosomes prior to meiosis II.

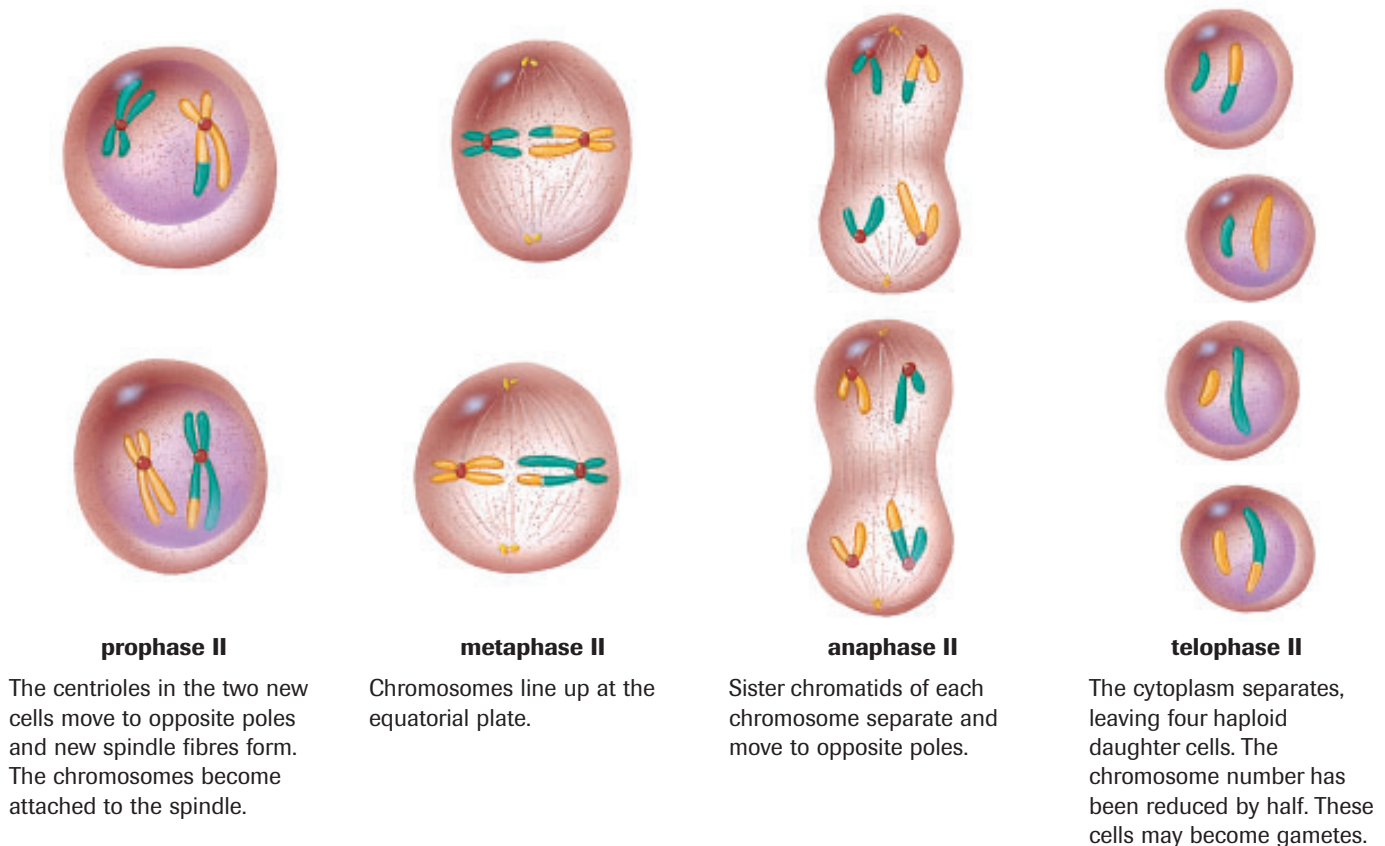


Figure 4  During meiosis II, sister chromatids separate.

Prophase II signals the beginning of the second meiotic division. During this stage, the nuclear membrane dissolves and the spindle fibres begin to form.

Metaphase II follows prophase II. It is signalled by the arrangement of the chromosomes, each with two chromatids, along the equatorial plate. The chromatids remain pinned together by the centromere.

Anaphase II can be identified by the breaking of the attachment between the two chromatids and by their movement to the opposite poles. This stage ends when the nuclear membrane begins to form around the chromatids, now referred to as chromosomes.

The cell then enters its final stage of meiosis: telophase II. During this stage, the second nuclear division is completed and then the second division of cytoplasm occurs. Four haploid daughter cells are produced from each meiotic division.

Practice

1. Define meiosis. Describe the main stages in the process. Sketch the sequence of stages to help you in your description. Label your diagrams appropriately.
2. How are haploid cells different from diploid cells in humans?
3. What is a tetrad?
4. What are homologous chromosomes?
5. Do homologous chromosomes have the same number of genes? Explain.
6. Do homologous chromosomes have identical genes? Explain.

mini Investigation

Gamete Formation in Grasshoppers

Obtain prepared slides of grasshopper (**Figure 5**) testes and identify cells undergoing meiosis. Make a few sample diagrams of cells at various stages of cell division.

- (a) Label the chromosomes.
- (b) Are you able to count the chromosome number? Explain why or why not.
- (c) Explain and compare what happens in prophase, metaphase, and anaphase of meiosis I and II.
- (d) How do cells undergoing meiosis II differ from cells undergoing meiosis I?

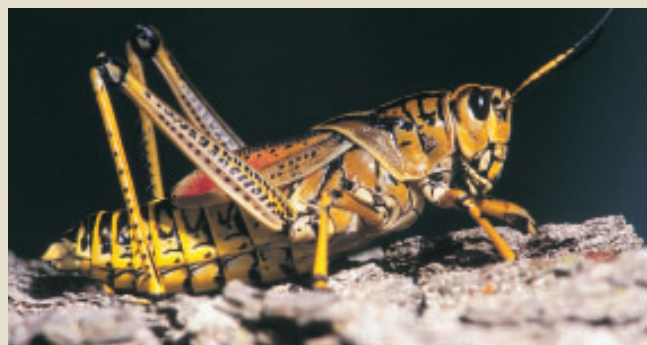


Figure 5

Comparing Mitosis and Meiosis

Single-celled eukaryotic species undergo asexual reproduction by mitosis, followed by cytokinesis. In multicellular eukaryotic species, somatic cells undergo these same processes in order to grow and repair tissue. In contrast, meiosis occurs only in the sex cells of multicellular eukaryotic species, in order to produce the gametes needed for sexual reproduction.

The most significant difference between mitosis and meiosis is the end result (**Figure 6**). Mitosis results in two daughter cells that are identical to each other. The daughter cells have the same genetic information and carry the same number of chromosomes as the

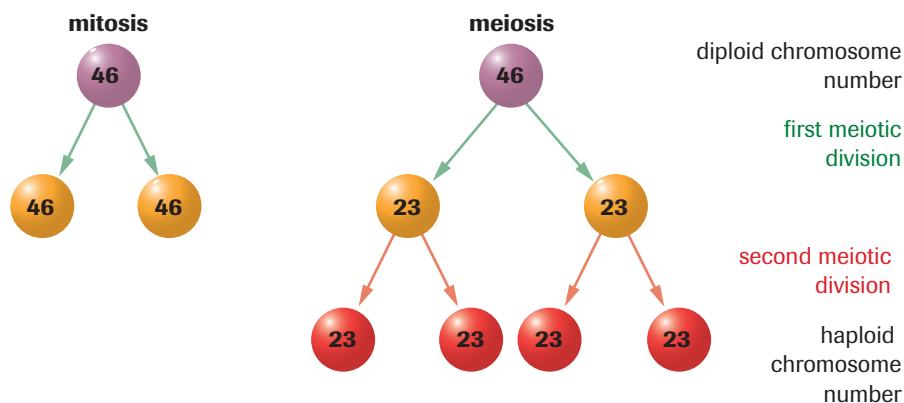


Figure 6

Comparison of mitosis and meiosis in humans. Mitosis produces two diploid cells from one diploid cell. Meiosis produces four haploid cells from one diploid cell.

parent cell. In contrast, meiosis results in four daughter cells that are different from each other and from the parent cell. The daughter cells have different genetic information from each other and from the parent cell and carry half the number of chromosomes as the parent cell.

Figure 7 and **Figure 8** (next page) summarize the similarities and differences between mitosis and meiosis. As you examine **Figures 7** and **8**, make note of the chromosome number of the cell or cells, whether the chromosome number is haploid or diploid, and during which stage the chromosome number changes.

Meiosis, combined with fertilization, explains the variation in traits that is observed in species that reproduce sexually. The variation occurs through three mechanisms. First, crossing over during prophase I exchanges genes on the chromosomes. Second, during metaphase I, the paternal and maternal chromosomes are randomly assorted. Although homologues always go to opposite poles, a pole could receive all the maternal chromosomes, all the paternal ones, or some combination. Lastly, during fertilization, different combinations of chromosomes and genes occur when two gametes unite.

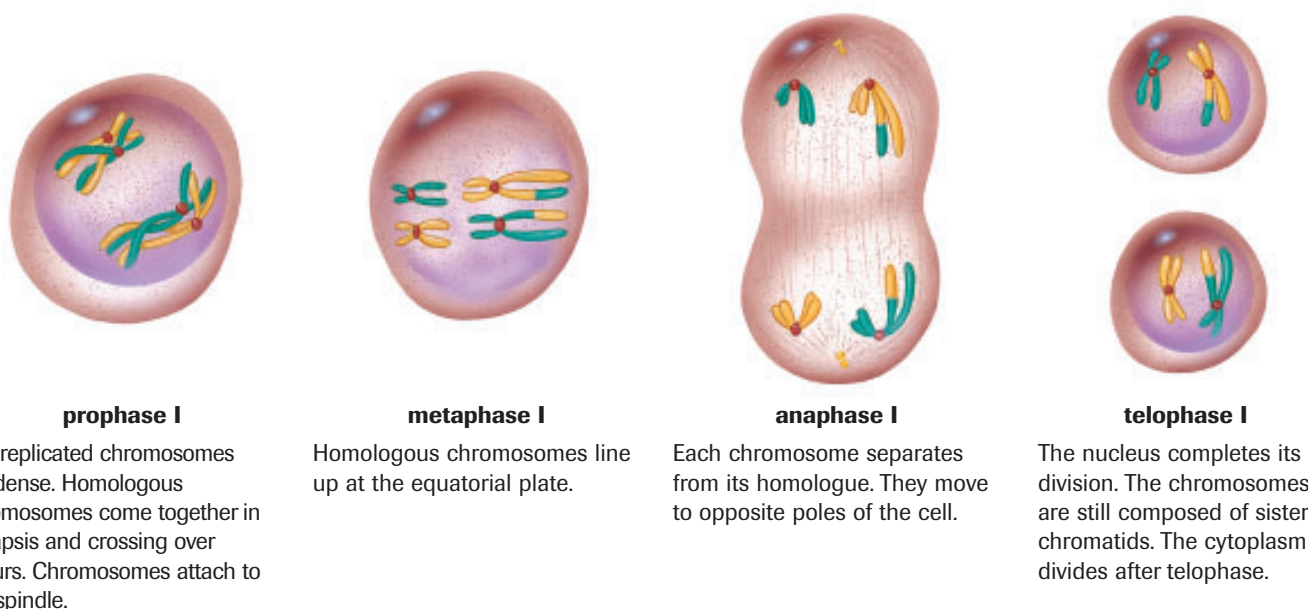


Figure 7

Stages of meiosis I. During meiosis I, crossing over occurs and homologous pairs separate. These events do not occur during mitosis.



INVESTIGATION 17.3 Introduction

Comparing Mitosis and Meiosis

Scientists often use models to help them to understand complex processes. To understand the consequences of mitosis and meiosis, you must have a clear view of the similarities and differences between these two modes of cell division. In this investigation, you construct and use models to investigate these essential processes.

Report Checklist

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| <input checked="" type="radio"/> Problem | <input type="radio"/> Materials | <input checked="" type="radio"/> Evaluation |
| <input type="radio"/> Hypothesis | <input type="radio"/> Procedure | <input type="radio"/> Synthesis |
| <input type="radio"/> Prediction | <input type="radio"/> Evidence | |

To perform this investigation, turn to page 590.

(a) Mitosis**prophase**

The chromosomes condense, becoming shorter and thicker. The centrioles assemble and spindle fibres attach to the centromeres of the chromosomes. The nuclear membrane starts to dissolve.

**metaphase**

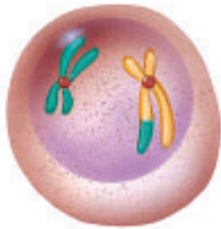
Chromosomes line up at the equatorial plate. The nuclear membrane completely dissolves.

**anaphase**

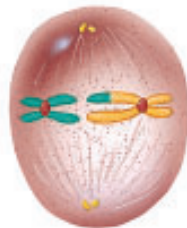
The centromeres divide and the resulting chromosomes, formerly chromatids, move to opposite poles of the cell. An identical set of chromosomes moves to each pole.

**telophase**

Chromosomes lengthen again, the spindle fibres dissolve, and a nuclear membrane forms around the chromosomes.

(b) Meiosis II**prophase II**

The centrioles in the two new cells move to opposite poles and new spindle fibres form. The chromosomes become attached to the spindle.

**metaphase II**

Chromosomes line up at the equatorial plate.

**anaphase II**

Sister chromatids of each chromosome separate and move to opposite poles.

**telophase II**

The cytoplasm separates, leaving four haploid daughter cells. The chromosome number has been reduced by half. These cells may become gametes.

Figure 8

Comparison of the stages in **(a)** mitosis and **(b)** meiosis II. In mitosis, homologous chromosomes are separated, giving rise to genetically identical sister cells. In meiosis II, the sister chromatids in the products of meiosis I separate as the cells divide again. This gives rise to four genetically different sex cells.

Practice

7. Copy and complete **Table 1**. Compare the chromosome number in the organisms before, during, and as a result of meiosis. Indicate whether the chromosome number is haploid or diploid.

Table 1 Chromosome Number in Cells of Four Organisms

	Human	Cat	Shrimp	Bean
Before meiosis				
chromosome number (haploid or diploid?)	46	?	?	?
number of pairs of homologous chromosomes	23	?	127	?
After meiosis I				
chromosome number (haploid or diploid?)	23	19	?	?
After meiosis II				
chromosome number (haploid or diploid?)	23	?	?	11
number of pairs of homologous chromosomes	0	?	?	?

gametogenesis the formation of gametes (sex cells) in animals

ootid an unfertilized ovum

Development of Male and Female Gametes

The formation of sex cells during meiosis is referred to as **gametogenesis**. Although human male and female gametes both follow the general process of meiosis, some differences do exist. The cytoplasm of the female gametes does not divide equally after each nuclear division. As shown in **Figure 9**, one of the daughter cells, called the **ootid**, receives most of the cytoplasm. The other cells, the polar bodies, die, and the nutrients are absorbed by the body of the organism. Only one ovum (egg cell) is produced from meiosis. In contrast, with sperm cells, there is an equal division of cytoplasm. Sperm cells have much less cytoplasm than egg cells. Sperm cells are specially designed for movement: they are streamlined and cannot carry excess weight. Egg cells use the nutri-

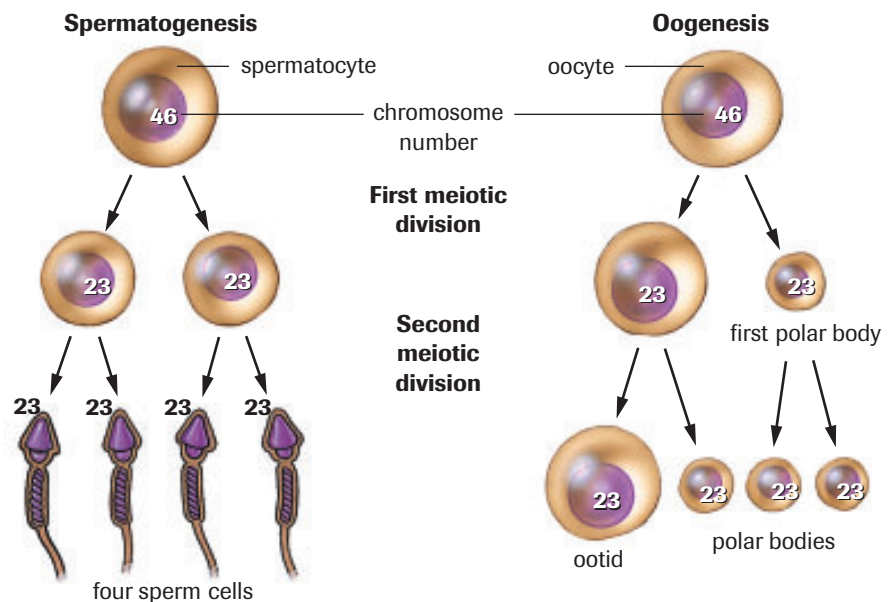


Figure 9 Generalized diagram of sperm and egg cell formation in humans

ents and organelles carried within the cytoplasm to fuel future cell divisions in the event that the egg cell becomes fertilized.

Human males make many more sex cells than females. The diploid spermatocytes—the cells that give rise to sperm cells—are capable of many mitotic divisions before meiosis ever begins. Males can produce one billion sperm cells every day. At birth, human females have about two million primary oocytes in their ovaries. Primary oocytes have already entered meiosis I, but they will remain suspended in prophase I until the female reaches reproductive age, or puberty. Starting at the first menstrual cycle, meiosis will resume in one oocyte at a time, once a month.



Case Study—Comparing Life Cycles of Plants

In this Web-based Case Study, you will observe and compare the life cycles of different plants. By examining the reproductive life cycles of plants you will gain a greater understanding of how reproductive diversity contributes to the evolution of complex organisms.

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Cell Division and Life Cycles

Organisms that undergo asexual reproduction produce offspring by mitosis. In this type of life cycle, cells divide by mitosis and give rise to daughter cells with the same chromosome number as the parent cell. There is no change in chromosome number. Examples of organisms that reproduce asexually are bacteria and yeasts.

In contrast, the chromosome number changes during the life cycle of a species that undergoes sexual reproduction. Examples of sexually reproducing species include flowering plants and birds. Two events in sexual reproduction change chromosome number: meiosis and fertilization. The gametes are formed by meiosis; these cells have half the chromosome number as the somatic cells. During fertilization, two gametes join to form a zygote, and the chromosome number is restored to that of the somatic cells.

There are variations in these two main types of the life cycles. **Figure 10**, on the next page shows a common life cycle found in flowering plants. In flowering plants, pollen contains the male sex cells, and the female egg cells are stored within the flower. The gametes contain a haploid chromosome number ($1n$). At fertilization, a diploid zygote ($2n$) is formed. The zygote undergoes mitosis to produce seeds, which then undergoes further mitosis to produce the adult $2n$ plant, called the sporophyte. Specialized cells in the mature $2n$ plant undergo meiosis to produce haploid ($1n$) spores. The spores then undergo mitosis to produce a mature, multicellular gametophyte. In most flowering plants, the gametophyte is too small to see without magnification. Since mitosis does not change chromosome number, the gametophyte is also haploid ($1n$). Specialized cells in the gametophyte develop into gametes, and the cycle begins again. Many familiar plants are sporophytes, such as the pine trees in a boreal forest. In other plant species, such as ferns, it is the gametophyte that is the larger, dominant form.

Figure 11, on the next page shows a common life cycle for animals, such as humans. In this life cycle, the gametes (sperm cells and egg cells) are haploid ($1n$) and single-celled. During fertilization, the gametes fuse and form a diploid ($2n$) zygote. This zygote undergoes mitosis to form the multi-cellular diploid adult body. Specialized cells in the adult body (in humans, cells in the testes and ovaries) undergo meiosis to produce gametes. Up to this point, the life cycles of plants in **Figure 10** and of animals in **Figure 11** are the same. However, the gametes of most animals do not undergo mitosis to form a multi-cellular gametophyte. Instead, the haploid stage remains single celled. When these haploid gametes unite, fertilization occurs and the life cycle begins again.

+ EXTENSION

Reproductive Strategies for Survival (Non-Human)

The different species on our planet have a remarkable variety of strategies to ensure their survival. Review some of these reproductive strategies by completing this extension activity.

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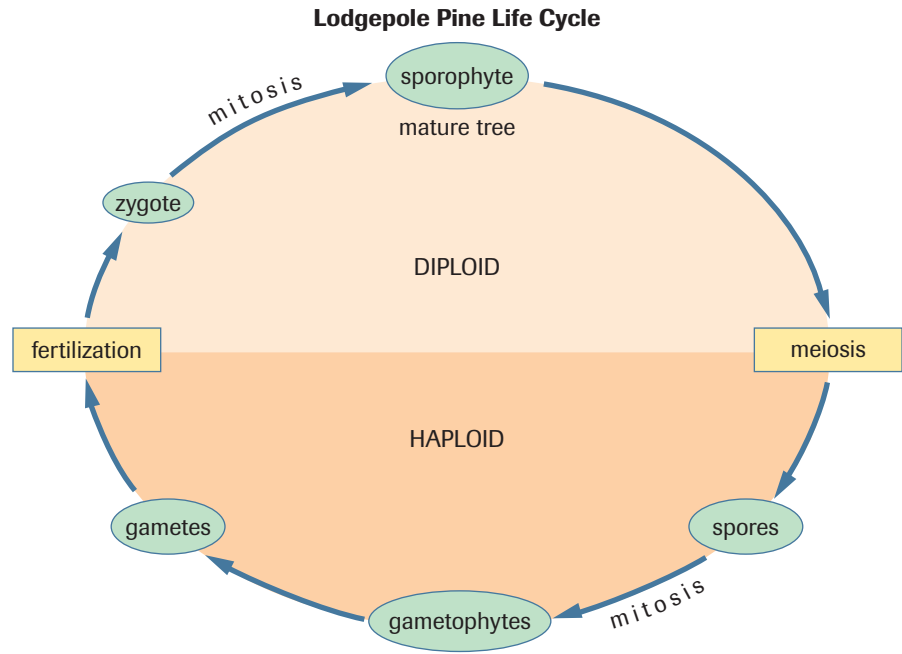
DID YOU KNOW?

Two Styles of Life Cycle

Some species undergo both sexual and asexual life cycles. For example, the spider plant can reproduce by seeds (sexual reproduction) or by runners (asexual reproduction). Aphid females reproduce asexually when the environment is stable, and sexually when the environment changes. Similarly, the male drones in a honey bee colony are produced by asexual reproduction, but the female workers and the queens are products of sexual reproduction.

Figure 10

Lodgepole pine life cycle. The diploid cells formed at fertilization undergo mitosis to form the multicelled *sporophyte* (the tree). The haploid stage starts when meiosis produces spores. These undergo mitosis to form a multicellular gametophyte, which is contained in the cones.



Human Life Cycle

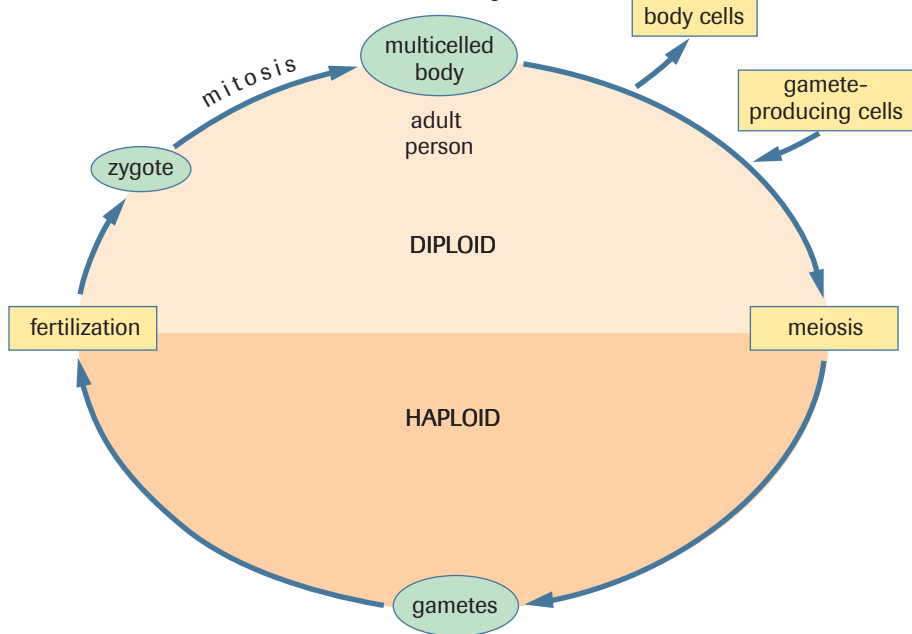


Figure 11

Human life cycle. The diploid cells formed at fertilization undergo mitosis to form the multicelled body. The haploid stage is the single-celled gametes.

SUMMARY Meiosis

- Meiosis involves the formation of sex cells or gametes. All gametes produced by meiosis have haploid chromosome numbers.
- Cells undergoing meiosis pass through two divisions.
- Homologous chromosomes are similar in shape, size, gene arrangement, and gene information.
- Crossing over is the exchange of genetic material between homologous chromosomes that occurs during meiosis.

Section 17.3 Questions

- How does the first meiotic division differ from the second meiotic division?
- Explain why synapsis may lead to the exchange of genetic information.
- Construct a table to compare meiosis with mitosis. How does meiosis differ from mitosis?
- A muscle cell of a mouse contains 22 chromosomes. Based on this information, how many chromosomes are there in the following types of mouse cells?
 - daughter muscle cell formed from mitosis
 - egg cell
 - fertilized egg cell
- Compare the mechanisms of gametogenesis in males and females.
- When meiosis occurs in females, the cytoplasm is not divided equally among the resulting four cells. Explain why.
- Compare the life cycles of plants and animals.
- Figure 12** shows sperm cell production following meiosis.
 - Which cells do not contain homologous pairs?
 - If the chromosome number for cell A is 12, indicate the chromosome number for cell C.

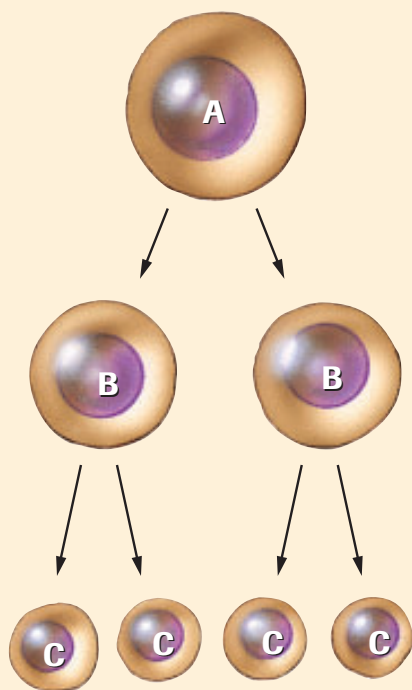


Figure 12

Sperm cell production in humans

- Use **Figure 13** to answer the questions below.
 - Which process(es) identify mitosis? Explain your answer.
 - Which process(es) identify meiosis? Explain your answer.

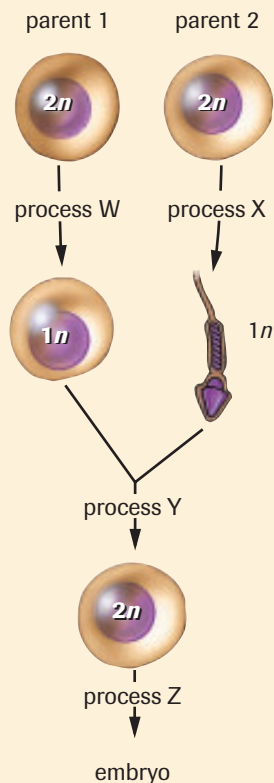


Figure 13

The processes and number of sets of chromosomes involved in the production of an embryo in humans

- King Henry VIII of England had some of his wives executed for not producing sons. Indicate why a little knowledge of meiosis might have been important for Henry's wives.
- A microscopic water animal called *Daphnia* can be reproduced from an unfertilized egg. This form of reproduction is asexual because male gametes are not required. Indicate the sex of the offspring produced. Explain your answer.

17.4 Abnormal Meiosis

nondisjunction the failure of a pair of homologous chromosomes to separate properly during meiosis

polyploidy a condition in which an organism has more than two complete sets of chromosomes

trisomy the condition in which there are three homologous chromosomes in place of a homologous pair

monosomy the condition in which there is a single chromosome in place of a homologous pair

Meiosis, like most processes of the body, is not immune to mistakes. **Nondisjunction** occurs when two homologous chromosomes fail to separate during meiosis or mitosis. The result is that one of the daughter cells will have too many chromosomes, while the other will have too few. Cells that lack genetic information, or have too much information, will not function properly. Nondisjunction can also occur in any cell during mitosis, but the effects are most devastating during the formation of sex cells in meiosis.

Some organisms have more than two complete chromosome sets. This condition is called **polyploidy**. Polyploid organisms may have three chromosome sets (triploidy or $3n$), four chromosome sets (tetraploidy or $4n$), and rarely, even more than four chromosome sets. Polyploidy can result when a diploid ($2n$) egg cell is fertilized by a haploid ($1n$) sperm, giving rise to a $3n$ cell. Nondisjunction of all chromosomes within the egg cell produces a diploid sex cell, which then becomes triploid upon fertilization. Tetraploid organisms are most often produced by the failure of the $2n$ zygote to divide after replicating its chromosomes. Following normal mitosis a $4n$ embryo is formed. Polyploidy is common in plants. Wheat, oats, tobacco, and potatoes are agriculturally important polyploid species. Plant geneticists may use chemicals that create errors in meiosis and mitosis to create new polyploid plants.

In humans, nondisjunction produces gametes with 22 and 24 chromosomes. The gamete with 24 chromosomes has both chromosomes from one of the homologous pairs. If that gamete joins with a normal gamete of 23 chromosomes from the opposite sex, a zygote containing 47, rather than 46, chromosomes will be produced. The zygote will then have three chromosomes in place of the normal pair. This condition is referred to as **trisomy**. However, if the sex cell containing 22 chromosomes joins with a normal gamete, the resulting zygote will have 45 chromosomes. The zygote will have only one of the chromosomes rather than the homologous pair. This condition is called **monosomy**. Once the cells of the trisomic or monosomic zygotes begin to divide, each cell of the body will contain more or fewer than 46 chromosomes.



Figure 1
Dr. Renée Martin



Canadian Achievers—Dr. Renée Martin

Pregnancy loss, birth defects, and mental retardation have been linked with chromosome abnormalities in sperm and eggs, but much of the scientific research to date has focused on abnormalities in the egg. Dr. Renée Martin (**Figure 1**), a medical geneticist from the University of Calgary, is recognized for her research on chromosomal abnormalities in human sperm cells. A research centre at the university has been named after her. Dr. Martin's research indicates that 10 % of sperm in normal men have a chromosomal abnormality, but men who have undergone radiotherapy have much higher frequencies of abnormal sperm. One of the most important questions to be answered is whether or not any of these abnormal sperm cells actually fertilize an egg. Dr. Martin's research will provide valuable information on birth defects and miscarriages. Visit the Nelson Web site to learn more about Dr. Martin's research contributions.

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Nondisjunction Disorders

Nondisjunction is associated with many different human genetic disorders. For example, Down syndrome is a trisomic condition. Down syndrome is also called trisomy 21 because it usually results from three copies of chromosome 21. People with Down syndrome (Figure 2) can be identified by several common traits, regardless of race: a round, full face; enlarged and creased tongue; short height; and a large forehead. Down syndrome is generally associated with mental retardation, although people with this condition retain a wide range of mental abilities. The risk of having a baby with Down syndrome increases with the age of the mother. About 1 in 600 babies is born with Down syndrome.

Turner syndrome occurs when sex chromosomes undergo nondisjunction. This monosomic disorder produces a female with a single X chromosome. In the egg cell, both homologous X chromosomes move to the same pole during meiosis I (Figure 3). When the egg with no X chromosome is fertilized by a normal sperm cell with an X chromosome, a zygote with 45 chromosomes is produced. Individuals with Turner syndrome appear female, but do not usually develop sexually and tend to be short and have thick, widened necks. About 1 in every 3000 female babies is a Turner syndrome baby. Most Turner syndrome fetuses are miscarried before the 20th week of pregnancy.

Klinefelter syndrome is caused by nondisjunction in either the sperm or egg (Figure 3). The child inherits two X chromosomes—characteristic of females—and a single Y chromosome—characteristic of males. The child appears to be a male at birth; however, as he enters sexual maturity, he begins producing high levels of female sex hormones. Males with Klinefelter syndrome are sterile. It has been estimated that Klinefelter syndrome occurs, on average, in 1 of every 500 male babies.

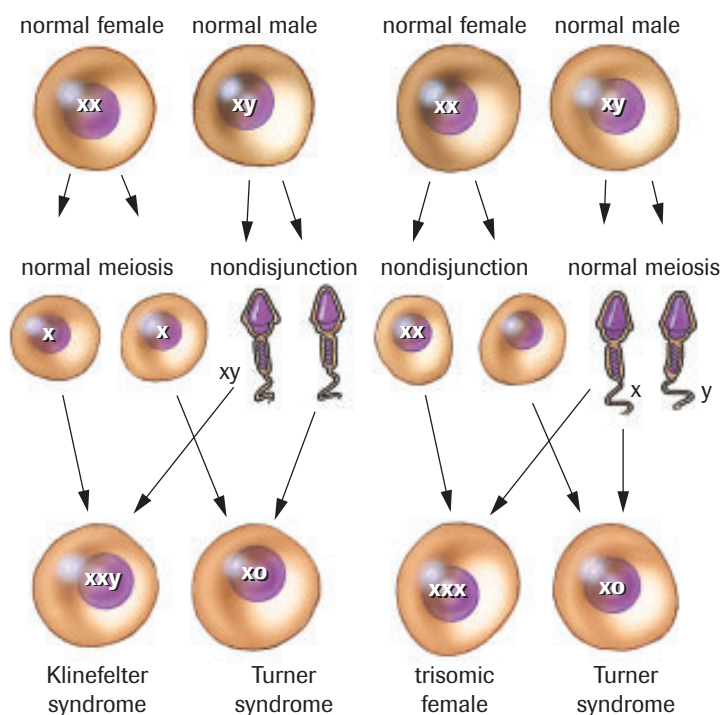


Figure 3

Nondisjunction disorders in humans

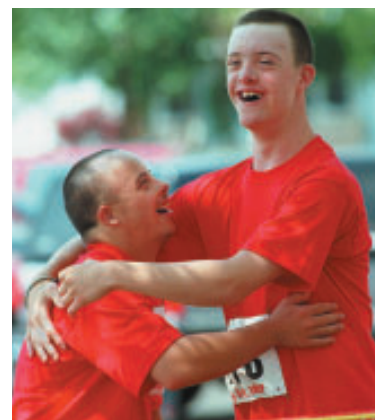


Figure 2

People with Down syndrome have a wide range of abilities.

CAREER CONNECTION



Geneticist

Geneticists are professionals with specialized education, training, and experience in genetics. Those with expertise in medical genetics may help families understand birth defects and how diseases are inherited. They may counsel people who carry genes that increase their risk of developing disease, such as some forms of cancer.

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karyotype chart a picture of chromosomes arranged in homologous pairs

+ EXTENSION



Karyotype Preparation

This animation depicts the steps involved in preparing a karyotype chart. You can also see representative karyotypes from individuals with nondisjunction disorders.

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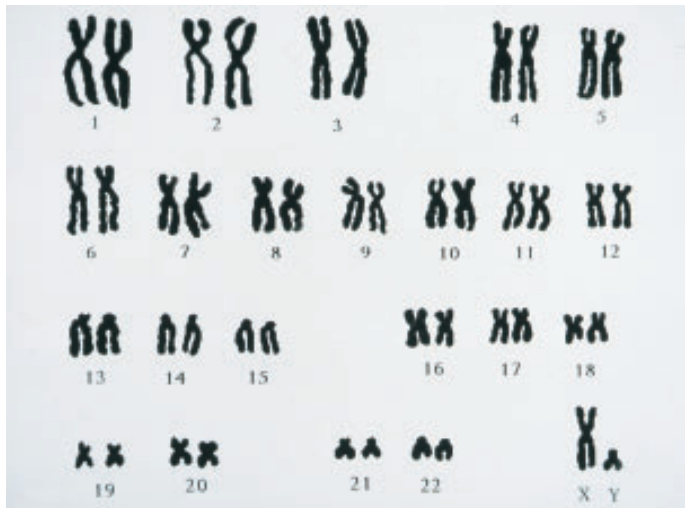


Karyotype Charts

One tool for detecting the results of abnormal meiosis is a chart of the chromosomes called a karyotype. Technicians obtain a **karyotype chart** by mixing a small sample of tissue with a solution that stimulates mitotic division. A different solution is added which stops division at metaphase. Since chromosomes are in their most condensed form during metaphase—their size, length, and centromere location are most discernible—it is the best phase in which to obtain a karyotype. The metaphase cells are placed onto a slide and then stained, so that distinctive bands appear. A photograph of the chromosomes is taken. The image is enlarged, and each chromosome is cut out and paired up with its homologue. Homologous chromosomes are similar in size, length, centromere location, and banding pattern. Finally, all the pairs are aligned at their centromeres in decreasing size order. The sex chromosomes are always placed last.

Figure 4 shows karyotypes of a normal male and of a female with Down syndrome. In about 95 % of cases, a child with Down syndrome has an extra chromosome in chromosome number 21. This trisomic disorder is produced by nondisjunction; the person has too much genetic information. Compare the chromosomes of a male shown in **Figure 4 (a)**, with the chromosomes of a female who has Down syndrome, shown in **Figure 4 (b)**. Notice how the chromosomes are arranged in pairs.

(a)



(b)

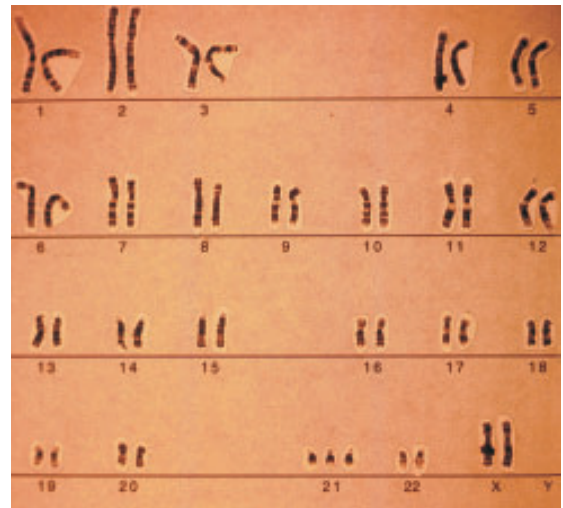


Figure 4

- (a)** Karyotype chart of a male with 46 chromosomes. Notice that the chromosome pair number 23 is not homologous. Males contain an X and a Y chromosome. They act as a homologous pair in meiosis, but they are not similar in size and shape as are the other chromosome pairs.
- (b)** Karyotype of a female with Down syndrome. Note the trisomy of number 21. Down syndrome affects both males and females.

▶ SAMPLE exercise 1

Figure 5 shows the incomplete karyotype chart of a human. Notice that several chromosomes are missing. Identify where chromosomes a to f (**Figure 6**) should be in this karyotype chart.

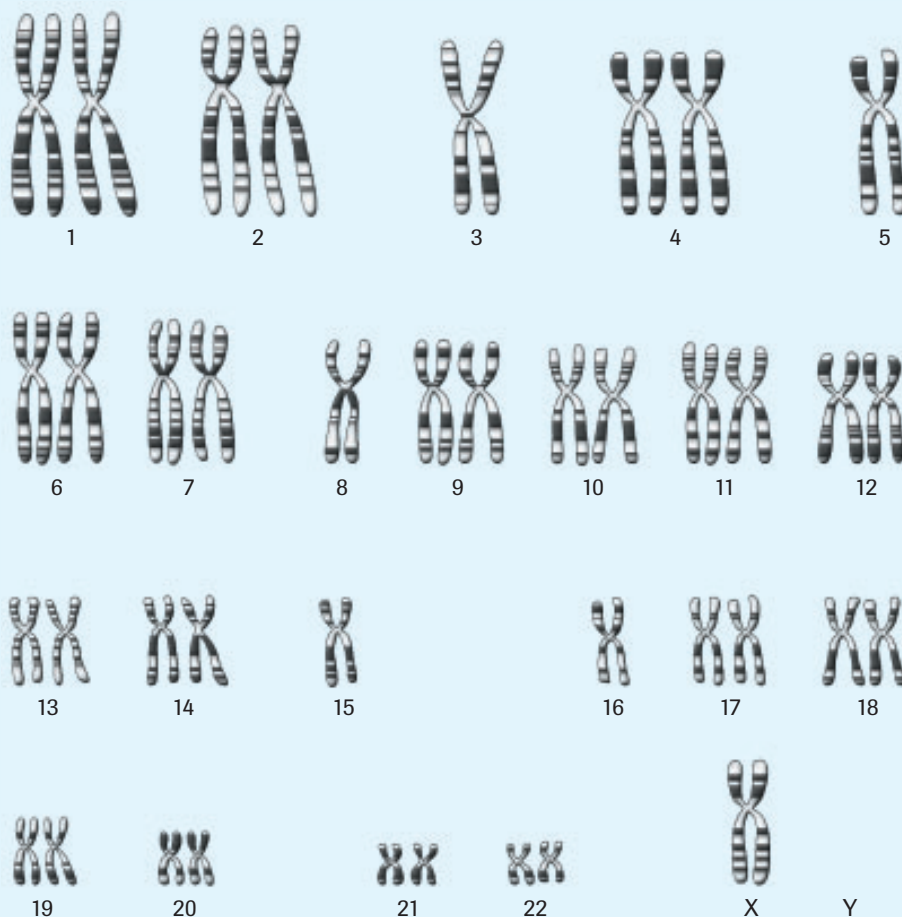


Figure 5

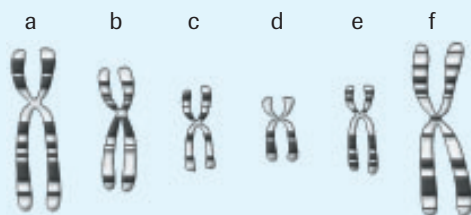


Figure 6

Solution

1. Start by scanning the karyotype chart to see which pairs are missing a chromosome. Pairs 3, 5, 8, 15, and 16 need a partner.
2. Match the most obvious chromosomes first: the longest, shortest, or most distinctively banded chromosomes.
3. For chromosome matches that are not as obvious, look carefully at the banding pattern and location of the centromere.

DID YOU KNOW?

Amniocentesis

A diagnostic technique known as amniocentesis can be used to test for nondisjunction and other genetic disorders in developing fetuses. During this procedure, a fine needle is inserted into the amniotic sac that surrounds the fetus, and about 10 mL of the amniotic fluid in which the fetus is bathed is withdrawn. This fluid contains fetal cells that can be used to produce a karyotype chart, as well as chemicals that may signal specific disorders.

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Learning Tip

You can also construct a karyotype chart using a copy of the chromosome images. For the Sample Exercise and Practice question 1, copy **Figures 5, 6** and **7**. Then, cut out the chromosome images in **Figures 6** and **7**, and position them on **Figure 5** according to their size, shape, and banding patterns.

+ EXTENSION

Karyotyping

There are a number of human genetic disorders that involve nondisjunction. In this Virtual Biology Lab, you will construct karyotype charts and use them to predict genetic disorders, in much the same way as a genetic counsellor might.

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4. Always pay attention to the X and Y chromosomes. In **Figure 5**, on the previous page, the missing chromosome might be X or Y. If it is Y, it will have to be found through elimination since it will not match X.

a, 5 b, 8 c, 16 d, Y e, 15 f, 3

► Practice

1. This person has either Down syndrome or Klinefelter syndrome. Identify the placement of chromosome g (**Figure 7**) to identify which of these two disorders the patient has.

g



Figure 7

WWW WEB Activity

Web Quest—Modelling Mitosis and Meiosis

Cellular division is one of the most critical processes an organism regularly undergoes. Unfortunately, errors during cellular division can result in a number of genetic syndromes such as Down syndrome, Turner syndrome, Klinefelter syndrome, and XYY syndrome. In this Web Quest, you will explore normal and abnormal cellular division. You will use the knowledge that you gathered to create an animation or presentation that shows exactly how abnormal cellular divisions occur.

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SUMMARY *Abnormal Meiosis*

- Nondisjunction occurs when two homologous chromosomes move to the same pole during meiosis. In humans, this produces gametes with 22 and 24 chromosomes.
 - Trisomy: a zygote containing 47 chromosomes; causes human genetic disorders such as Down syndrome and Klinefelter syndrome
 - Monosomy: a zygote containing 45 chromosomes; causes Turner syndrome
- A karyotype chart is a picture of chromosomes arranged in homologous pairs in descending order by size, with the sex chromosomes placed last.

► Section 17.4 Questions

1. What is nondisjunction?
2. Differentiate between monosomy and trisomy.
3. What is Down syndrome?
4. What is a karyotype?
5. What is Turner syndrome?
6. Use a diagram to illustrate how nondisjunction in meiosis I ($2n = 4$) differs from nondisjunction in meiosis II.

INVESTIGATION 17.1

Frequency of Cell Division

In this activity, you will view and compare cells from onion cells and from a whitefish blastula in various stages of mitosis. Because slides are used, the cell divisions you will be viewing are frozen in time. Therefore, it will not be possible for you to watch a single cell progress through the stages of mitosis. Based on your observations, you will determine the frequency of cell division and construct a clock representing the division cycle, given the time taken to complete one cycle of mitosis. In a table, you will record the number of cells in each stage of mitosis.

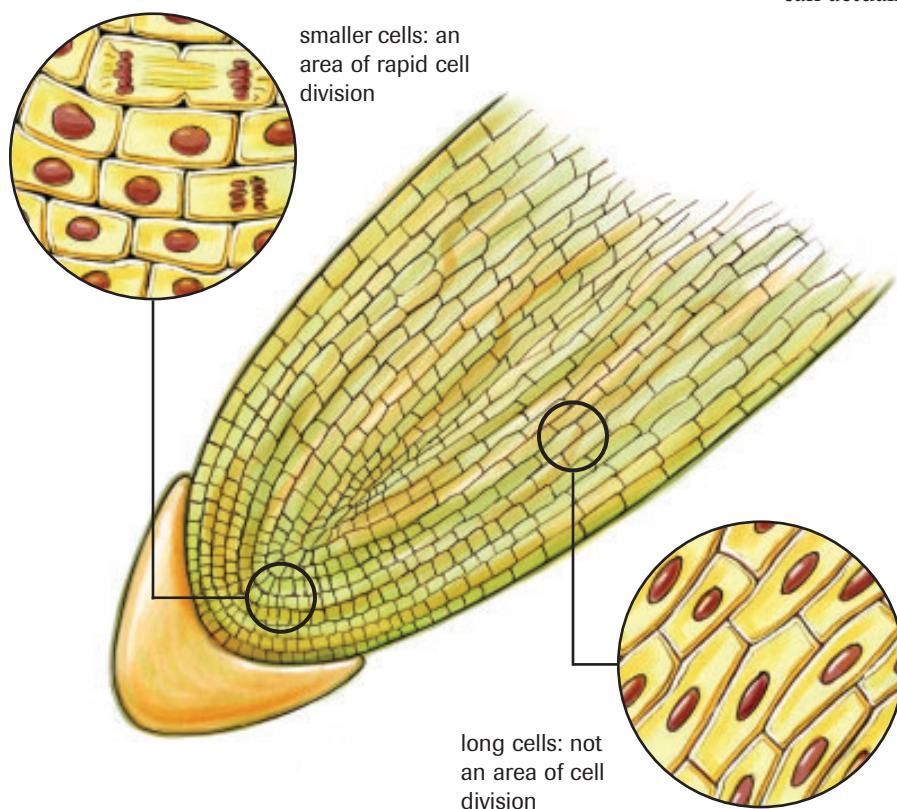
Materials

microscope	prepared slides of onion root tip
lens paper	prepared slides of whitefish blastula

Procedure

Part 1: Observing Dividing Cells

1. Obtain an onion root tip slide and place it on the stage of your microscope. View the slide under low-power magnification. Focus using the coarse-adjustment knob.



Report Checklist

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2. Centre the root tip in the field of view and then rotate the nosepiece to the medium-power objective lens. Focus the image using the fine-adjustment knob. Observe the cells near the root cap. This area is referred to as the meristematic region of the root.
3. Move the slide to view the cells away from the root tip. These are the mature cells of the root. Record the differences between the cells of the meristematic area and the mature cells of the root. Draw a diagram to help you (**Figure 1**).
4. Return the slide to the meristematic area and centre the root tip. Rotate the nosepiece to the high-power objective lens. Use the fine adjustment to focus the image.
5. Locate and observe cells in each of the phases of mitosis. It will be necessary to move the slide to find each of the four phases. Use **Figure 1** as a guide. Draw, label, and title each of the phases of mitosis. It is important to draw only the structures that you can actually see under the microscope.

Figure 1

Meristematic region of the onion root tip where the cells are actively growing and dividing

INVESTIGATION 17.1 *continued*

6. Return your microscope to the low-power objective lens and remove the slide of the onion. Place the slide of the whitefish blastula on the stage. Focus with the coarse-adjustment knob. Repeat the procedure that you followed for the onion cells and, in the whitefish blastula, locate dividing cells under high-power magnification. Note how different the animal cells are compared to the plant cells.

Part 2: Determining the Frequency of Cell Division

7. Count 20 adjacent whitefish blastula cells and record whether the cells are in interphase or division phase. Record the number of cells in interphase and the number of cells that are actively dividing.
8. Repeat the same procedure for the meristematic region of the plant root.

Part 3: Creating a Cell-Division Clock

9. Under high-power magnification, locate 50 onion root cells that are dividing. Do not include cells that are between divisions. Identify the phase of mitosis each cell is in. Record the number of cells in each phase.
10. Repeat the procedure for the cells of the whitefish blastula.

Analysis and Evaluation

Part 1: Observing Dividing Cells

- (a) How do the cells of the meristematic area differ from the mature cells of the root?
- (b) Why were plant root tip cells and animal blastula cells used for viewing cell division?
- (c) Explain why the cells that you viewed under the microscope do not continue to divide.
- (d) Compare and contrast cell division in plant and animal cells. Use a Venn diagram to organize your ideas.

Part 2: Determining the Frequency of Cell Division

- (e) For both the plant and animal cells, calculate the percentage of cells that are dividing. Use the following formula:

$$\frac{\text{Number of cells dividing}}{\text{Total number of cells counted}} \times 100 = \text{___ \% dividing}$$

- (f) For both plant and animal cells, create a circle graph showing the percentage of cells in division phase and the percentage of cells in interphase. Label the diagrams appropriately. Compare the graphs. How are they different? How are they the same?

Part 3: Creating a Cell-Division Clock

- (g) For both plant and animal cells, calculate the percentage of cells that are in each of these four phases: prophase, metaphase, anaphase, and telophase.
- (h) For each cell type, construct a circle graph showing the percentage of cells in each phase of mitosis. Include labels and titles.
- (i) If it takes 16 h to complete one cycle of mitosis for whitefish and 12 h for onions, determine the time spent in each phase. Include this information in your circle graphs.

Synthesis

- (j) The number of animal cells in each phase of mitosis was recorded in **Table 1**. If the time taken to complete one cycle of mitosis was 15 h, create a cell-division clock to represent the data.

Table 1 Number of Cells in Different Phases of Mitosis

Mitotic phase	Number of cells in phase
prophase	15
metaphase	20
anaphase	10
telophase	5

INVESTIGATION 17.2

Identification of a Cancer Cell

Purpose

To identify cancerous cells and to recognize the differences between cancerous and non-cancerous cells

Materials

light microscope
lens paper
prepared slide of squamous cell carcinoma

Procedure

1. Clean the microscope lenses with lens paper. Rotate the revolving nosepiece to the low-power objective lens. Place the slide of the carcinoma on the stage of the microscope and bring the image into focus using the coarse-adjustment knob.
2. Locate the dermal and epidermal layers. Draw a line diagram showing the position of the epidermal and dermal cell layers. Determine and record whether the cells of the epidermis are invading the dermis.
3. Rotate the revolving nosepiece to the medium-power objective lens. Locate a cancerous cell. **Figure 1** is an example of cancerous cells. Use the fine-adjustment knob to bring the image into focus. Observe how cells of the carcinomas have a much larger nucleus. They appear pink in colour and often have an irregular shape.

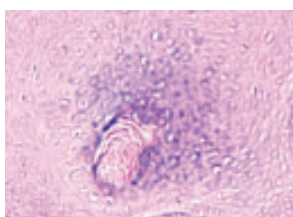


Figure 1

Report Checklist

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4. Rotate the nosepiece to high-power magnification, and bring the image into focus using the fine-adjustment knob.
5. Estimate and record the size of the cell, in micrometres (μm).
6. Estimate and record the size of the nucleus of the same cell, in micrometres (μm).
7. Rotate the revolving nosepiece to the medium-power objective lens and locate a normal cell. Rotate the nosepiece to the high-power objective lens, and bring it into focus with the fine-adjustment knob. **Figure 2** is an example of normal cells.

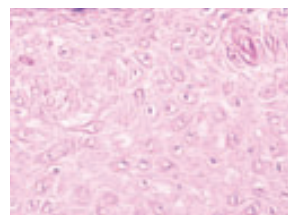


Figure 2

8. Repeat steps 5 and 6 for the normal cell.

Analysis

- (a) Using the formula below, determine the nucleus-to-cytoplasm ratio for the cancerous cell and for the normal cell.

Evaluation

- (b) Compare the cancerous and normal cells in a table similar to **Table 1**.

Table 1

Cell type	Cell size	Nuclear shape	Nuclear size	Nucleus-to-cytoplasm ratio
normal cell				
cancerous cell				

INVESTIGATION 17.2 *continued*

Synthesis

- (c) Cancerous cells are often characterized by a large nucleus. Based on what you know about cancer and cell division, provide an explanation for the enlarged nucleus.
- (d) Why are malignant (cancerous) tumors a greater threat to life than benign tumors?
- (e) Provide a hypothesis that explains why the skin is so susceptible to cancer.
- (f) A scientist finds a group of irregularly shaped cells in an organism. The cells demonstrate little differentiation, but the nuclei in some of the cells stain darker than others.
 - (i) Based on these findings, would it be logical to conclude that the organism has cancer? Justify your answer.
 - (ii) What additional tests might be required to prove or disprove the hypothesis that the cells are cancerous?

INVESTIGATION 17.3

Comparing Mitosis and Meiosis

In this investigation, you will model and compare the events of mitosis and meiosis. In this model, you will create homologous chromosomes that have the same size and shape, but different colours. This will show that they are similar but not identical.

Materials

red modelling clay plastic knife
blue modelling clay sheets of paper
green modelling clay pencil

Procedure

For each step, make a coloured sketch of your model with appropriate labels. Include brief descriptions of your steps and make sure to use the same step numbers as given.

Part 1: Mitosis

- Take some red clay and roll it between your hands to create a piece 10 cm long and about as thick as your finger. Make another piece about 5 cm long.
- Repeat step 1 with the blue clay.
- Make an identical copy of each piece of clay. Then attach the identical pieces with a green ball of clay (**Figure 1**).
- Draw a line down the length of a sheet of paper. Line up the four chromosomes along the line (**Figure 2**).

Report Checklist

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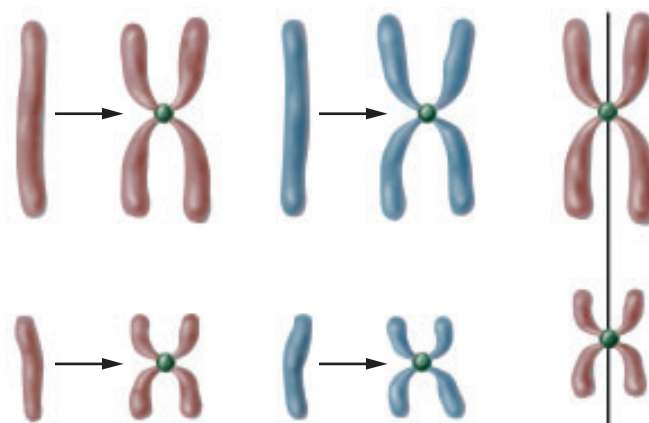


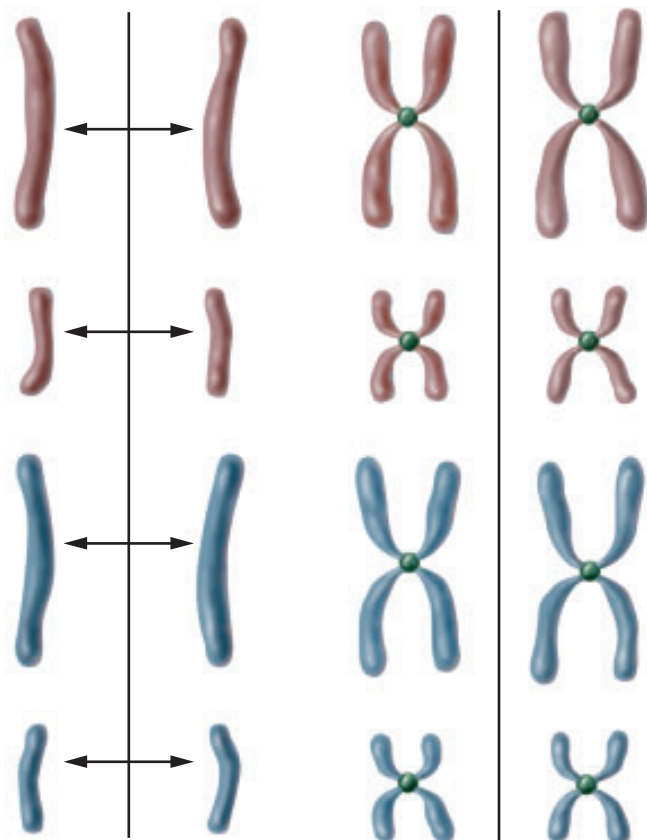
Figure 1

- Remove the green balls and move each of the single pieces of clay to opposite ends of the paper (**Figure 3**, next page).
- Before every mitotic division, each chromosome is duplicated during interphase. Make an identical copy of each piece of clay as before (**Figure 4**, next page).

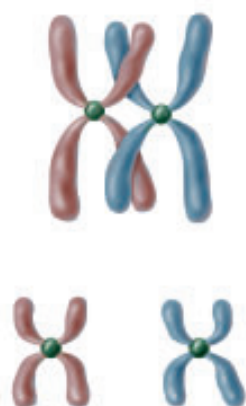
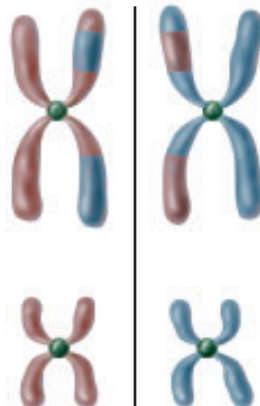
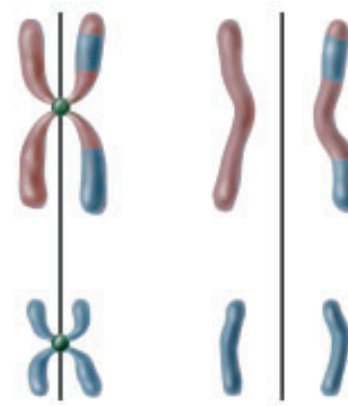
Part 2: Meiosis

- Follow steps 1 to 3 from part 1.

Figure 2

INVESTIGATION 17.3 *continued*
**Figure 3****Figure 4**

8. Demonstrate crossing over. Break off a piece of clay from one chromosome and attach it to the other chromosome (**Figure 5**). Repeat a few times if you like.
9. To simulate metaphase I, place the chromosomes on either side of the equatorial plate, represented by a line drawn on a piece of paper (**Figure 6**).

**Figure 5****Figure 6****Figure 7**

10. Choose one of the haploid daughter cells and line the chromosomes up along the equatorial plate. Remove the centromere and move chromosomes to opposite poles (**Figure 7**).

Analysis and Evaluation
Part 1: Mitosis

- (a) In step 3, what process did you model?
- (b) What do the red and blue pieces of clay represent? What do the green balls of clay represent?
- (c) In step 4, what is the diploid chromosome number of the cell?
- (d) What phase of mitosis does the model represent?
- (e) In step 5, what structure do the single pieces of clay represent after separation?
- (f) What phase of mitosis does the model represent?
- (g) In step 6, how many chromosomes are in each of the daughter cells?
- (h) Compare the daughter cells with the parent cell.

Part 2: Meiosis

- (i) In steps 1 to 3, on what basis are chromosomes considered to be homologous?
- (j) What is the diploid chromosome number?
- (k) In step 8, what must happen before the homologous chromosomes can cross over?
- (l) In which phase does crossing over occur?
- (m) What happens during crossing over?
- (n) In step 9, how does metaphase I of meiosis differ from metaphase of mitosis?
- (o) What is the haploid chromosome number?
- (p) In step 10, compare the resulting daughter cells of mitosis and meiosis.

Outcomes

Knowledge

- define and explain the significance of chromosome number in somatic and sex cells (i.e., haploidy, diploidy and polyploidy) (17.3, 17.4)
- explain cell cycle events (i.e., interphase, including G1, S, and G2 phases, chromosomal behaviour in mitosis and cytokinesis) (17.1)
- describe spermatogenesis and oogenesis and the reduction of chromosomal number in meiosis (17.3)
- compare the processes of mitosis and meiosis (17.3)
- describe the processes of crossing over and nondisjunction in terms of stages, replication, and resultant chromosome numbers and evaluate their significance to variation in organism inheritance and development (17.4)
- compare the formation of fraternal and identical offspring in a single birthing event (17.1)
- describe the diversity of reproductive strategies by incorporating the principles of mitosis and meiosis when comparing the alternation of generations in a range of organisms (17.3)

STS

- explain that science and technology are developed to meet societal needs and expand human capability (17.2, 17.4)

Skills

- ask questions and plan investigations of questions, ideas, problems, and issues (all)
- gather and record data and information by performing a simulation to demonstrate the behaviour of chromosomes during mitosis (17.1); use a microscope and prepared slides of onion root tip cells to identify the stages of a cell cycle, and calculate the duration of each stage; research and compare a range of reproductive strategies in organisms and present them in charts, tables, or diagrams (17.3)
- analyze data and apply mathematical and conceptual models by preparing and interpreting models of human karyotypes (17.4)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

17.1

somatic cell	chromatin
cell cycle	centromere
mitosis	sister chromatids
cytokinesis	centriole
interphase	spindle fibre

17.2

enucleated	telomere
stem cell	

17.3

meiosis	crossing over
haploid	gametogenesis
diploid	ootid
homologous chromosomes	polar body
tetrad	oocyte
synapsis	

17.4

nondisjunction	monosomy
polyploidy	karyotype chart
trisomy	

► MAKE a summary

- Sketch the processes of meiosis and mitosis and show the differences between them. Label the sketch with as many of the key terms as possible. Check other sketches and use appropriate designs to make your sketch more clear.
- Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

► Go To

www.science.nelson.com 

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 17
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

+ EXTENSION

CBC  QUIRKS & QUARKS

A Cure for Aging

Dr. Siegfried Hekimi, (professor of biology at McGill University), Dr. Michael West, (Chief Executive Officer of Advanced Cell Technology in Worcester Massachusetts), Dr. Cynthia Kenyon, (biochemistry and biophysics professor from the University of California, San Francisco), and Dr. Marc Tatar (Brown University in Rhode Island) all discuss the causes of aging and their research into slowing the aging process.

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Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. Select the diagram that represents metaphase.
 - A. Figure 1 (a)
 - B. Figure 1 (b)
 - C. Figure 1 (c)
 - D. Figure 1 (d)

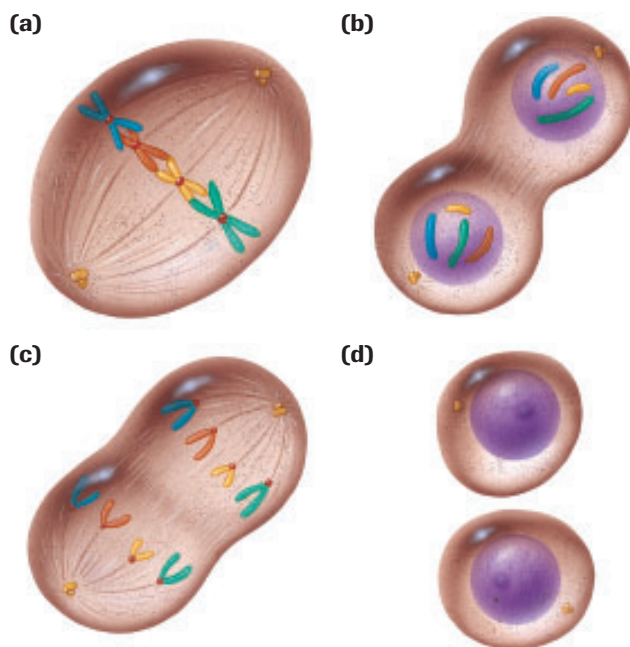


Figure 1

2. The following descriptions explain events in the various stages of a cell cycle. Arrange the description in the correct sequence of events. (Record all four digits of your answer.)
 1. Chromatids separate and move to opposite poles.
 2. Chromosomal alignment occurs in the equatorial plate.
 3. Chromosomes become longer and thinner.
 4. Chromosomes shorten and thicken.

Use the following information to answer questions 3 to 6.

A student observed three different areas in the mitotic region in an onion root tip. She counted the number of cells that were at each stage of the cell cycle at the time the root was killed and mounted on the slide. Her results are presented in **Table 1**.

Table 1 Number of Cells in Different Stages of Division

Phase	Number of cells			
	Area 1	Area 2	Area 3	Total
interphase	99	79	88	
prophase	12	14	16	
metaphase	6	4	5	
anaphase	0	2	2	4
telophase	2	3	4	9

3. According to the data in **Table 1**, the duration of the phases of the cell cycle, from the longest to the shortest, is
 - A. prophase, metaphase, anaphase, telophase, interphase
 - B. interphase, prophase, metaphase, telophase, anaphase
 - C. interphase, prophase, metaphase, anaphase, telophase
 - D. not possible to list, since the number of cells and not the duration was observed
4. Calculate the percentage of cells in prophase. (Record your answer as a value rounded to one decimal place.)

NR
5. If the total time for the completion of one cell cycle is 660 min, determine the time required to complete metaphase. (Record all four digits of your answer.)

NR
6. Calculate the percentage of cells undergoing mitosis. (Record your answer as a value rounded to one decimal place.)

NR
7. A researcher studied the growth rate of a malignant cell in mice. Every two days, he counted the number of cells in a 1 mm² area, over a period of two months. Select the graph in **Figure 2**, on the next page, that represents the data collected.
 - A. Figure 2 (a)
 - B. Figure 2 (b)
 - C. Figure 2 (c)
 - D. Figure 2 (d)

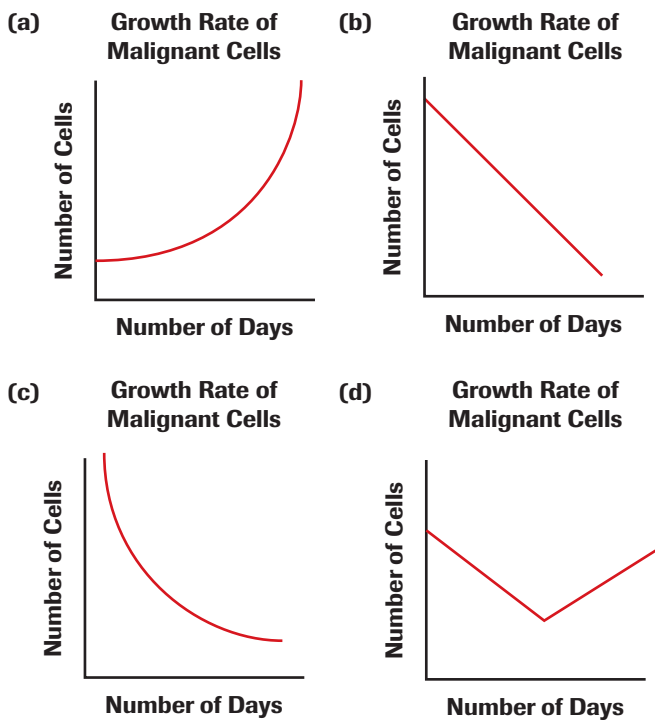


Figure 2

Use the following information to answer questions 8 to 10.

Figure 3 shows the early events in fertilization of a human egg and sperm, and development of the embryo. The numbers refer to the number of chromosomes.

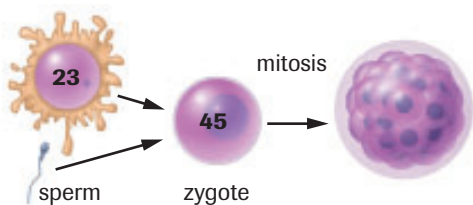


Figure 3

8. Select the number of chromosomes that were in the sperm cell.
 - A. 20
 - B. 22
 - C. 23
 - D. 45
9. Select the number of homologous pairs of chromosomes that would be in the zygote if it were female.
 - A. 21
 - B. 22
 - C. 23
 - D. 24

10. Select the number of chromosomes that would be in each blastula cell, following mitosis.
 - A. 20
 - B. 22
 - C. 23
 - D. 45

11. Indicate which of the following cells would be capable of meiosis:
 - A. brain cells
 - B. fat cells
 - C. cells of a zygote
 - D. sperm-producing cells of the testes

Part 2

12. **Figure 4** shows plant and animal cells during cell division.
 - (a) **Identify** each cell as either a plant or an animal cell. **Justify** your answer.
 - (b) **Identify** the phases of cell division.

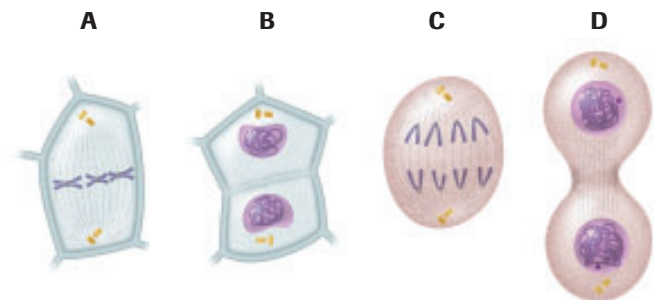


Figure 4

13. **Explain** why a better understanding of the mechanism of cell division may enable scientists to regenerate limbs.
14. **Explain** why the formation of calluses on the hands provides evidence that cell division can be stimulated by cell damage.
15. **Explain** how it is possible to produce a trisomic XXX female.
16. **Sketch** a diagram that shows the kind of nondisjunction that would cause a male and female each with an abnormal number of chromosomes to produce an XYY offspring.
17. If nondisjunction disorders could be eliminated by screening sperm and egg cells, sperm and egg banks could all but eliminate many genetic disorders. **Describe** the social, moral, and ethical implications to society of the systematic elimination of genetic disorders in humans.

Use the following information to answer questions 18 and 19.

Table 2 shows data collected from two different fields of view while examining hamster embryo cells. The number of cells found in each of the cell phases was recorded. It took 660 min to complete one cycle from interphase to interphase.

Table 2

Cell phase	Area 1	Area 2	Total cell count	Time spent in phase
interphase	91	70	?	?
prophase	10	14	?	?
metaphase	2	1	?	?
anaphase	2	1	?	?
telophase	4	4	?	?

18. Copy **Table 2** into your notebook, **determine** the missing values, and complete the table. To calculate the time spent in interphase, for example, you would use the following equation:

$$\frac{\text{Number of cells in interphase}}{\text{Total number of cells counted}} = \frac{\text{Time spent in phase}}{\text{Total time of cycle (660 min)}}$$

19. Using the data provided, **sketch** a circle graph showing the amount of time spent in each phase of the cell cycle.

20. **Identify** one advantage of using a cutting instead of using seeds to grow a new plant.

Use the following information to answer questions 21 to 25.

Fruit flies normally have eight chromosomes. Flies with fewer chromosomes die before maturity. **Figure 5** shows the process of meiosis in three fruit flies.

21. **Identify** the parent in which nondisjunction takes place.
22. **Identify** how many chromosomes would be in zygotes D, E, and F.
23. **Describe** what is happening during process X.
24. **Identify** which zygote would most likely be healthy.
25. **Identify** by name the conditions that the other zygotes have.

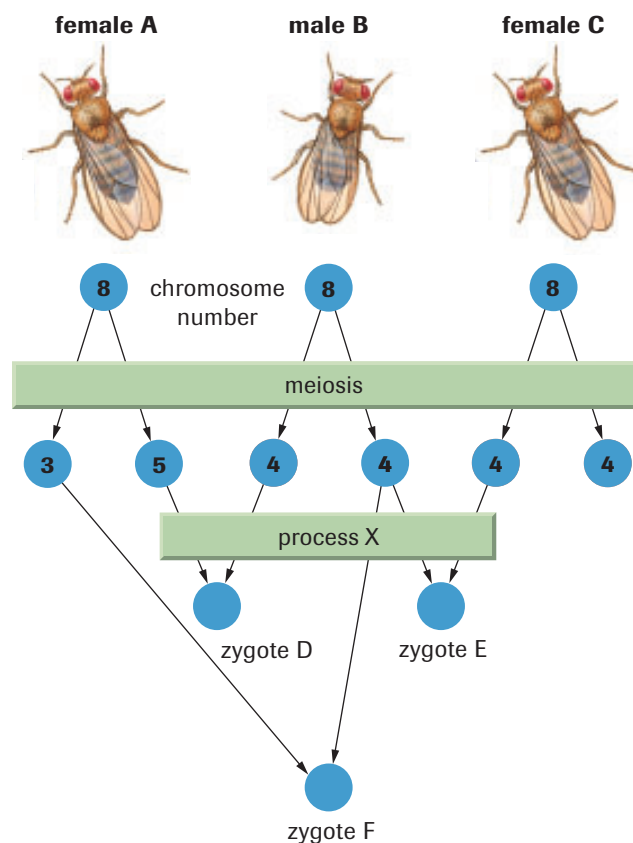


Figure 5

26. Twins can be either identical or fraternal. Write a unified response that includes the following aspects of twins:
- Copy **Table 3** in your notebook. **Identify** with a check mark (✓) the statements that you believe are always, or almost always, true for fraternal twins and for identical twins.
 - Justify** each choice.

Table 3

Descriptor	Fraternal twins	Identical twins
They have the same blood type.	?	?
They are the same sex.	?	?
They like the same hockey team.	?	?
They have the same mass.	?	?
They have the same hair colour.	?	?
They know what the other one is thinking.	?	?